Future Themes in Water Management in the Context of Global Change

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Final report

for the project:

Analysis of Potentially New Themes in Water Management – Future Trends and Research Needs

(Analyse zu Potentiellen Neuen Themenfeldern im Wasserbereich – Forschungstrends und Forschungsbedarf)

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1 Introduction

Water resources management has become an important theme on the scientific and political agendas. The importance of the international dimension and impacts of global change have moved in the centre of attention. Numerous national and international programmes have addressed water related themes. The German Ministry of Education and Research (BMBF) has funded several major research programmes on Integrated Water Resources Management and Global Change. The goal of this study is to make recommendations for promising future research themes by analysing the international water research and policy landscape and by taking stock of recent achievements. The study has thus the following objectives:

- Provide an overview of recent and emerging developments in topical research areas in the field of water resources of high scientific and political relevance.
- Evaluate research themes with respect to their potential for scientific breakthroughs, political impact and suitability for the German water community.
- Develop recommendations for a future research programme of the BMBF.

Time line of work:

Based on a preliminary assessment the following six cluster themes of high political relevance and major research needs were identified:

1. Adaptation to climate change
2. Food and water – virtual water flows
3. Urbanisation and infrastructure
4. Disasters and vulnerability to water related threats
5. Water governance (cross-cutting)
6. Ecosystem water requirements – environmental flows (cross-cutting)

During the first phase of the project these core themes were further elaborated based on interviews, expert reports and a detailed literature screening regarding the recent and emerging developments in topical research areas in the field of water resources and an evaluation of the research themes regarding their potential for scientific breakthroughs and political impact. Criteria of the evaluation were:

- Gaps in scientific knowledge and potential to achieve scientific breakthroughs
- Relevance of international policy problem
- Suitability of the programme to be implemented in the German scientific community (critical stock of available expertise, potential to strengthen an emerging research community)
- Science-policy interplay - link to relevant stakeholders, efficiency and effectiveness of implementation, potential of a programme to have a real impact

At the end of the first phase a wide range of relevant themes (80 in total) were identified. Hence, the following tasks characterised the second phase of the project. First of all, a prioritisation of the research themes was needed in order to identify those knowledge gaps in water management in the context of global change that are most significant in terms of both their scientific relevance and their political impact. In line with this first task, a sound synopsis of all research questions was needed in order to reduce redundancies and gain best syntheses. Also the further development of future research topics had to be considered: what are the requirements for a thorough investigation of the research themes and how to achieve best results in future projects of water management? On the basis of these tasks final recommendations were developed for a future research programme of the BMBF.

To ensure a sound expert basis for further work a two-day expert workshop **"Future trends and research needs in water management"** was organised in February 2010 in Osnabrück. About 25 national and international experts of water research and management were invited. The goal of the workshop was to discuss the main results of this milestone report, to cluster the different topics of the assessment and give joint recommendations for promising future research themes and their operationalisation in future German research programmes. After a first screening of relevant future research topics in this field of research (based on the results of the first project period) an in-depth analysis by distinguished scientists was conducted, and yielded the following Thematic Clusters prioritised and proposed by application areas:

1. **Food and Water in 21st Century**
   - Development of a Global Water and Food Framework
   - Water and Food in Africa from a Global Perspective
   - Water and Food in Big Cities from a Global Perspective
   - Water and Food in South-East Asia from a Global Perspective
2. **Water related risks, vulnerability, adaptive capacities**
   - Risk Governance and Institutional Vulnerability
   - Risk and adaptation related to urban dynamics
   - Vulnerability of coupled critical and supply infrastructures/ systems
3. **Governance of Transformation**
   - Developing and evaluating infrastructure transformation
   - From waste water treatment to urban metabolism
   - From flood protection to resilient regions
   - Accepting the limits: building resilience in water scarce regions
4. **Manipulating flow and water bodies for managing ecosystem services**
   - Functional linkages of coupled natural and technical aquatic ecosystems
   - Process based understanding of hydrological-ecological linkages and feedbacks, e.g. focus on carbon cycling, nitrogen cycling
   - Process based understanding of social-ecological linkages and feedbacks: how do societies depend on ecosystem services?
   - Management tools for implementation of environmental flows

Each thematic cluster was further developed with an analysis of the overall theme and an in-depth analysis of each application area. Thus the analysis of each thematic cluster is structured according to the following logic. First, an introduction into the theme is given, second a state of the art analysis of the different application areas is provided to conclude with research gaps and future research needs. Finally, a drafting of an outline of a potential research project for the thematic cluster is given. In order to define the relevance of each application area and the proposed research agenda for the thematic cluster, an evaluation was conducted according to the following criteria:

1. **Gaps in scientific knowledge and potential to achieve scientific breakthroughs**
   - Expected outcomes have the potential to open up an internationally visible and innovative research field.
   - Gaps in highly relevant fields with little indication of any large international programme addressing them.
   - Interdisciplinary approach needed to achieve scientific breakthroughs (preferably comprising collaboration between social and natural sciences)
   - Barriers to be overcome are judged to be surmountable in a research programme
2. **Science-policy interplay**
   - Link to relevant stakeholders, efficiency and effectiveness of implementation, potential of a programme to have a real impact
   - Policy problem is tangible enough that a research programme can provide meaningful policy advice within a limited time frame.
   - International relevance but scope for German or European policy to play a leading role.
   - Ongoing - developing policy process to which the programme can be linked.
3. **Relevance of international policy problem**
   - Policy problem is emergent, has been identified more recently and is currently
   - moving higher on the policy agenda.
   - Most likely to be persistent over the next decade and become even more urgent.
4. **Suitability of the programme to be implemented in the German scientific community**
   - Critical stock of available expertise in the German research community to address the issues.
   - Programme has the potential to strengthen an emerging research community (e.g. water governance)
   - Build in strengths and achievements in the German research community without duplication of previous programmes.
   - Support of developing collaborations between communities that have failed to do so in the past.

2 Theme Cluster 1: Water for Food in 21st Century

Authors: Nick van de Giesen, Peter Droogers and Walter Immerzeel

2.1 Introduction

2.1.1 Relevance

The German Ministry of Education and Research (BMBF) has funded several major research programmes on Integrated Water Resources Management and Global Change. Currently, BMBF is in the process to identify promising future research themes by analysing the international water research and policy landscape and by taking stock of recent achievements.

Based on a preliminary assessment the following themes of high political relevance and major research needs and potential have been identified:

1. Adaptation to climate change
2. Food and water
3. Urbanisation and infrastructure
4. Disasters and vulnerability to water related threats
5. Water governance (cross-cutting)
6. Ecosystem water requirements – environmental flows (cross-cutting)

This report contributes to theme 2 “Food and Water” and covers four so-called Application Areas:

- Development of a Global Water and Food Framework
- Water and Food in Africa from a Global Perspective
- Water and Food in Big Cities from a Global Perspective
- Water and Food in South-East Asia from a Global Perspective

Criteria used to describe the four Application Areas:

Gaps in scientific knowledge and potential to achieve scientific breakthroughs

- Expected outcomes have the potential to open up an internationally visible and innovative research field.
- Gaps in highly relevant fields with little indication of any large international programme dressing them.
- Interdisciplinary approach needed to achieve scientific breakthroughs (preferably comprising collaboration between social and natural sciences)
- Barriers to overcome are judged to be surmountable in a research programme

Science-policy interplay

- Link to relevant stakeholders, efficiency and effectiveness of implementation, potential of a programme to have a real impact
- Policy problem is tangible enough that a research programme can provide meaningful policy advice within a limited time frame
- International relevance but scope for German or European policy to play a leading role
- Ongoing and developing policy process to which the programme can be linked

Relevance of international policy problem

- Policy problem is emergent, has been identified more recently and is currently moving higher on the policy agenda
- Most likely to be persistent over the next decade and become even more urgent

Suitability of the programme to be implemented in the German scientific community

- Critical stock of available expertise in the German research community to address the issues
- Programme has the potential to strengthen an emerging research community (e.g. water governance)
- Build in strengths and achievements in the German research community without duplication of previous programmes
- Support of developing collaborations between communities that have failed to do so in the past

Box 1: Criteria used to describe the four Application Areas.

2.1.2 Trends in Food Demand

Food production will have to increase by 1-2% per year for the next generation in order to keep up with food demand. Increase in food demand is caused by a combination of population growth and changes in consumption patterns, especially an increase in animal-based protein in our diets (Liu & Savenije, 2008). The production of biofuels may, until the advent of so-called third generation biofuels, may put extra stress on grain and sugar production, although such stress will only be very localised (Hoogeveen *et al.*, 2009). The spike in food prices in 2008 (see Figure 1) has dampened but food prices are still 70% higher than they were five years ago. It has been known for a long time that the supply elasticity of food is low. World trade without dramatic productivity rises can, therefore, only be a limited solution.

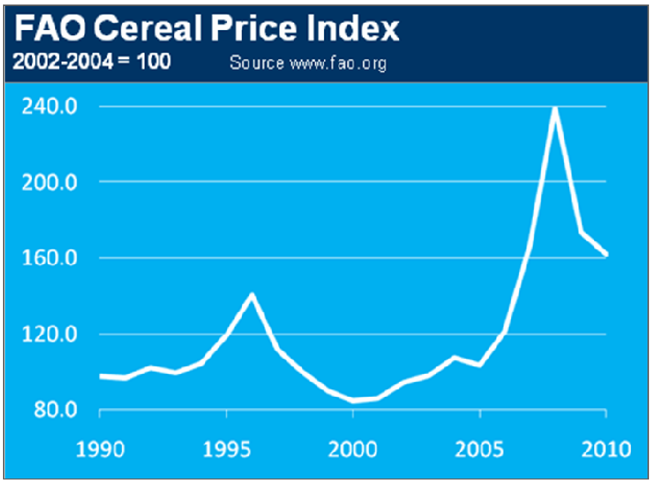

Figure 1: Commodity price development (Source: FAO).

Various global assessment studies exist using an integrated approach to assess trends in food demand with a linkage to water. The approaches followed by these global studies can be divided into two groups. On the one hand, studies exist that have a strong embedding in the economic science where physical (and hydrological) processes are to a large extent ignored. In these studies water-food issues are represented by simplified parametric equations and the main driving forces are considered to be the economic ones. These economics are often based on food demand and food supply. Typical examples include the work of the International Food Policy Research Institute (IFPRI) in Washington.

The other group of global studies on water and food interactions is based on strong hydrological assessment. The economics are assumed of lower importance and often limited to a post-calculation of the agro-hydrological results rather than a driving force. Some typical examples include the work on so-called AEZ (Agro-Ecological Zones) of the Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA). A more recent approach is the so-called LPJ-MAgPIE project (Lotze-Campen, Lucht, Müller, Bondeau, & Smith, 2005). It is based on and combines the Lund-Potsdam-Jena Dynamic Global VegetationModel (LPJ) and the "Management model of Agricultural Production and its Impact on the Environment" (MAgPIE) models. A prototype has been developed for Germany as well (Lotze-Campen *et al.*, 2008).

One common weakness in both approaches is the focus on average conditions. There are hardly any global studies that include the natural year-to-year variation in the analysis, while it is expected that the impact of climate change will not only alter mean values but also event-size distributions, which consequently will lead to a significant increase in extreme events.

An interesting synthesis paper was published recently looking at the global perspective of water and energy inputs in food production (Khan & Hanjra, 2008). The following list summarises the main findings of this review:

- Loss of natural habitat on agriculturally, utilisable land (Green, Cornell, Scharlemann, & Balmford, 2005).
- Increase in continental water storage facilities to store water formerly flowing to deltas, wetland and inland sinks and its impacts on greenhouse gases (Milly, Cazenave, & Gennero, 2003).
- Homogenisation of regionally distinct environmental templates / landscapes, due to an excessive construction of dams (Poff, Olden, Merritt, & Pepin, 2007), thereby altering natural dynamics in ecologically important flows on continental (Fig. 2) to global scales (Arthington, Bunn, Poff, & Naiman, 2006).
- Loss or extinction of freshwater fauna populations and loss of habitat for native fisheries, plummeting bird populations due to inadequate water flows, and loss of riverine biodiversity due to large scale hydrological changes in tropical regions (Dudgeon, 2000).
- Biodiversity loss associated with agricultural intensification (Butler, Vickery, & Norris, 2007; Kremen, Williams, & Thorp, 2002).
- Enhanced global movement of various forms of nitrogen between the living world and the soil, water, and atmosphere with serious and long-term environmental consequences for large regions of the Earth (Vitousek *et al.*, 1997).
- Nitrate pollution of agricultural landscapes and groundwater resources, and nitrogen- and phosphorous-driven eutrophication of terrestrial, freshwater, and near-shore marine ecosystems, causing unprecedented ecosystem simplification, loss of ecosystem services, species extinctions, outbreaks of nuisance species, shifts in the structure of food chains, and contribution to atmospheric accumulation of greenhouse gases (Correll, 1998; Tilman *et al.*, 2001).
- Synthetic chemicals compromising symbiotic nitrogen fixation, thus increasing dependence on synthetic agrochemicals and unsustainable long-term crop yields (Fox, Gulledge, Engelhaupt, Burow, & McLachlan, 2007).
- Soil salinity, water logging, impaired natural drainage, associated damages to infrastructure, and lost opportunities for regional growth and economic development (Khan *et al.*, 2006; Kijne, 2006; Wichelns & Oster, 2006).
- Depletion of groundwater aquifer and reduced stream flows (Khan, Mushtaq, Hanjra, & Schaeffer, 2008) with associated impacts on drinking water supplies, health and rural livelihoods (Meijer, Boelee, Augustijn, & Van Der Molen, 2006). Displacement of population due to dam construction (Cernea, 2003), higher incidence of vector-borne diseases in some irrigation areas, and loss of human productivity (Lautze *et al.*, 2007).
- Reduced capacities of ecosystems to sustain food production, maintain freshwater and forest resources, purify water, regulate climatic processes and air quality, or ameliorate infectious diseases (Foley *et al.*, 2005).
- Global accelerated erosion from plowed agricultural fields and hill slope production (greater than 1–2 orders of magnitude than rates of soil production), erosion under native vegetation, and long-term geological erosion (Montgomery, 2007).

- Erosion caused by human transport of larger amounts of sediment and rocks for construction and agricultural activities exceeding any other natural process operating on the surface of the planet (Wilkinson & McElroy, 2007).
- Extreme hydrological events such as storms, droughts and floods (Illangasekare *et al.*, 2006).
- Global inter- and intra-state conflict over freshwater resources and potential for social instability (Yoffe *et al.*, 2004).
- Raised threat level of global terrorism to water resources due to elevated risk to dams and reservoirs (Gleick, 2006; Mustafa, 2005).

These points mentioned by Khan and Hanjra (2008) can be considered as a starting point when identifying research priorities related to food and water in the context of global change. Another important report that provides a baseline for food production projections is the "Agriculture towards 2015/2030" report by the FAO. This report is based on the converging opinions of food and agricultural experts. The report has a conservative outlook in the sense that it uses low estimates for productivity increases, etc, and also does not take climate change into account.

Important conclusions of this study are that most of the population increase to 9 billion people in 2050 will take place in the developing world. Only 16% of the world food production finds its way into the international trade system, which means that most extra food will most likely to have to be grown in the developing world. Lifestyle changes will increase the average food supply to rise from 2650 Kcal/person/day in 2006 to 3000 Kcal/person/day in 2050. This implies that total aggregated agricultural production will need to increase by 2050 with 70% with respect to production levels in 2006.

The sources of production growth will come from expansion of arable land, increase in cropping intensity, and increase in yields. Yield increase estimates are modest at around 0.7% per year for the major grains as opposed to the 2.0% annual growth that was observed over the period 1961-2007.

Extra food production will be achieved differently in different places. In South and East Asia, intensification and additional irrigation will be important, whereas the food production increase in Africa and Latin America will mainly be achieved by extending the surface of arable land. Water will play an important role. The Middle East and North Africa are particularly under stress, both from a land and from a water point of view. Presently, 43% of total agricultural production in the world is produced on the 23% of the arable land that is being irrigated. The annual growth rate for irrigated area is estimated at around 0.7% for Africa and Latin America and at around 0.15% and 0.3 % for South and East Asia, respectively. The irrigation potential for Africa and Latin America will remain large compared to the irrigated areas, whereas in East Asia and in the Near East and North Africa, the total irrigated area approaches the total irrigation potential.

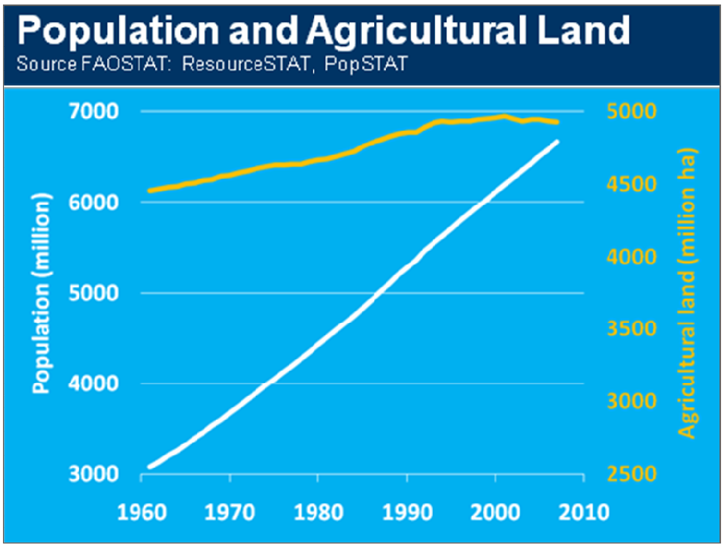

Figure 2: Global population growth and development of agricultural utilised area (Source: FAO).

2.1.3 Proposed Global Perspective Water-Food

From previous sections it is clear that global food production will have to increase and that water will be one of the main constraints to achieve this. At the same time other stressors like climate change, bio-fuels, improper management, global trade, and land grab will amplify, or at least increase uncertainty, about future water-food linkages.

Various global water-food analyses have been initiated over the last decade, but in most cases these analyses are somewhat biased towards one discipline. There is a big need to have a framework that integrates all domains relevant to the linkages between water and food: physics, economics, management, social aspects, land and trade.

The global water-food framework as proposed here includes four components, referred to as Application Areas: (i) development of a global water and food framework, (ii) Africa, (iii) big cities, and (iv) Asia. These Application Areas were selected based on a previous document (Droogers & Van De Giesen, 2009) and a scoping workshop (Osnabrück, Germany; 2/4-Feb-2010). The main outputs of the workshop with respect to the food and water theme are summarised in the following sections.

2.1.3.1 Development of a Global Water and Food Framework

An integrated public domain global water and food framework will be developed that enables to undertake scenario analysis with a strong emphasis on climate change. The framework will include physical aspects (water resources, land, climate), economics (food and land prices, global trade), management (water abstractions, efficiencies), and social aspects (water rights, poverty). The framework (data, models, scenarios, output) will be setup in a completely open source, Wiki-type environment, to ensure wider dissemination, quality control, and data and knowledge exchange.

2.1.3.2 Water and Food in Africa from a Global Perspective

The global framework to be developed requires a strong emphasis on Africa, where the most potentials and at the same time the biggest threats to food and water security occur now and in the future. The framework for Africa will be developed simultaneously with the global model but specific emphasis will be put on the economics of extensive foreign investments in land, closing yield-gaps and management aspects.

2.1.3.3 Water and Food in Big Cities from a Global Perspective

Big cities are largely ignored in current global water-food studies. However, urban agriculture, waste water irrigation, urban livestock, domestic water competition and food trade are key in global water-food analysis. For a few mega-cities these aspects will be studied and included in the global water and food framework. Based on these cities of the pilot studies all big cities will be implemented in the framework. Scenario analysis will indicate in which direction water-food issues will develop and what decisions could be taken for sustainable development.

2.1.3.4 Water and Food in South-East Asia from a Global Perspective

Water and food interrelationships are extremely high in Asia. High population concentrations, large dependency on erratic rainfall, huge irrigation schemes, vulnerability to sea-level rise, and complex water competition issues make the area extremely important from a global as well as regional perspective. The region will be studied in a multi-disciplinary way, with a strong focus on risk and vulnerability issues. The study will be developed simultaneously with the global water-food framework to ensure linkages between and within the region and the global scale.

2.2 Application Areas

2.2.1 Application Area 1: Development of a Global Water and Food Framework

Workshop "Future trends and research needs in water management"; 2nd to 4th February 2010 Osnabrück, Germany

Development of a Global Water and Food Framework

An integrated public domain global water and food framework will be developed that enables to undertake scenario analysis with a strong emphasis on climate change. The framework will include physical aspects (water resources, land, climate), economics (food and land prices, global trade), management (water abstractions, efficiencies), and social aspects (water rights, poverty). The framework (data, models, scenarios, output) will be setup in a completely open source, Wiki-type environment, to ensure wider dissemination, quality control, and data and knowledge exchange.

Box 2: Application Area 1 of the workshop "Future trends and research needs in water management".

Major Conclusions

Gaps in scientific knowledge

- At the global scale existing global frameworks such as the green and blue water framework could be improved by including management and adaptation options.
- There is a need for global crop water models that can quantify the demand and supply side of agricultural water at a large scale with sufficient physical detail.
- User-friendly decision support tools such as water allocation and planning tools and serious gaming tools are required to get the message across to decision makers.
- A dedicated data-portal that integrates public domain datasets on the interface of climate, hydrology, agriculture and socio-economics is in great demand.
- Basic datasets on water consumption and water productivity are largely lacking.

Science-policy interplay

- Food production will have to increase by 1-2% per year for the next generation in order to keep up with food demand.
- Improved technologies, innovation and policy shifts can achieve this required increase in agricultural productivity but research is of crucial importance.

Relevance of international policy problem

- The direct links with climate change, the tradeoff between food and bio-fuel production, the global economy and the increasing population has put the topic high on all international agendas.

German Scientific community

- German scientists from various universities have contributed significantly to the development of global models and datasets and already have a specific niche in this area.

Box 3: Major workshop conclusions in Application Area 1.

2.2.1.1 Gaps in Scientific Knowledge and Potential to Achieve Scientific Breakthroughs

Over the last three years two comprehensive global state-of-the-art studies on water and food have been presented. The first one, Comprehensive Assessment of Water Management in Agriculture (Molden, 2007) describes in 16 chapters the state of the art of water and food:

> *"The Comprehensive Assessment of Water Management in Agriculture critically evaluates the benefits, costs, and impacts of the past 50 years of water development, the water management challenges communities are facing today, and solutions people have developed. The results will enable better investment and management decisions in water and agriculture in the near future and over the next 50 years. The assessment is produced by a broad partnership of practitioners, researchers and policy makers."*

The main message of this comprehensive assessment is that if appropriate measures, including research, will be taken, food security can be achieved under current and future conditions. The analysis resulted in eight so-called policy actions, which have implications for setting the research agenda (Molden, 2007):

1. Change the way we think about water and agriculture
2. Fight poverty by improving access to agricultural water and its use
3. Manage agriculture to enhance ecosystem services
4. Increase the productivity of water
5. Upgrade rainfed systems—a little water can go a long way
6. Adapt yesterday's irrigation to tomorrow's needs
7. Reform the reform process—targeting state institutions
8. Deal with tradeoffs and make difficult choices

The second comprehensive studies on global water and food issues are undertaken by the UNESCO World Water Assessment Programme (WWAP, 2009 and WWAP, 2006). The key messages as described in the World Water Development Report (WWAP, 2006) are:

- To satisfy the growing demand for food between 2000 and 2030, production of food crops in developing countries is projected to increase by 67 percent.
- As competition for water increases among different sectors, irrigated agriculture needs to be carefully examined.
- Farmers are at the centre of any process of change and need to be encouraged and guided.
- Irrigation institutions must respond to the needs of farmers, ensuring more reliable delivery of water, increasing transparency in its management and balancing efficiency and equity in access to water.
- The agriculture sector faces a complex challenge: producing more food of better quality while using less water per unit of output.
- Action is needed now to adapt agricultural and rural development policies.

The key messages of the latest report, WWDR-2009, are summarised as:

- Population growth and rapid economic development have led to accelerated freshwater withdrawals.

- Trends in access to domestic water supply indicate substantial improvement in the past decade.
- Steadily increasing demand for agricultural products to satisfy the needs of a growing population continues to be the main driver behind water use.
- The recent acceleration in the production of biofuels and the impacts of climate change bring new challenges and add to the pressures on land and water resources.
- Freshwater ecosystems provide an extensive array of vital services to support human well-being.

This latest report of the WWAP included an interesting section on "How much do we know about water uses?" The report provides the following view on this:

> *"Our knowledge of water use is as poor as our knowledge of water resources – perhaps poorer. Information is largely incomplete – particularly for agriculture, the largest user – and is lacking altogether for some countries. Only limited disaggregated information exists, and even this shows deficiencies of validity and homogeneity and provides extremely poor information on trends. The quality of information systems varies with each country, but there are common difficulties:*
>
> - *Statistics on the magnitude of demand and withdrawal are often estimated rather than based on data that are measured or collected from censuses. The level of uncertainty varies, but is particularly high for agriculture.*
> - *Sectors of use are not defined homogeneously and are not well disaggregated.*
> - *Adequate historical datasets are rare, and the dates of available statistics are not always explicit.*
> - *Lack of agreed terminology leads to discrepancies in data compilation and analyses"*

Characteristics of both state-of-the-art studies are that substantial human (over 1000 contributors) and financial (over few million dollars) resources have contributed to the success and acceptance of the main findings. The studies have therefore a significant impact on science policy setting and set the scene for any additional global work in the area of water and food.

In order to implement the recommendations and research agendas set out by these comprehensive studies a framework is proposed that integrates physical and socio-economic aspects and covers the entire spectrum from data expert-knowledge, models and strategic decision support systems. The following key scientific gaps can be distinguished:

2.2.1.1.1 Conceptual Frameworks

There is a need for the development of new conceptual framework that should be used to guide the global water-food and climate change progress. In a recent special issue of the Journal of Hydrology devoted to the green blue water initiative (GBI) some key concept are discussed that could be used as a starting point for further development (Hoff, 2010). The authors describe a concerted effort to quantify at global scale, geographically explicit and process-based, the full green and blue water resource, integrating water and land management. The distinction between green and blue water is a strong concept and analysis shows that globally, green water use by crops is about 4–5 times larger than consumptive blue water use (Hoff *et al.*, 2010). Further improvements of the framework could focus on further inclusion of management and adaptation options such as such as rainwater harvesting, small scale storage, supplementary irrigation, improved irrigation and fertilisation, as well as expansion of agricultural land, virtual water trade and investments in agricultural water management have been quantified by the different models.

2.2.1.1.2 Global Models and Decision Support Systems

At the global scale there is a need for models and tools that can be used to analyse the interaction between crop water demand and use and water availability at the scale of large river basins. Several global models exist and further developments should build on these efforts. A good example specifically aimed at quantifying green and blue water and virtual water flows is the global crop water model (GWCM) developed by Siebert and Doll (2010). GWCM computes consumptive water use (evapotranspiration) and virtual water content (evapotranspiration per harvested biomass) of crops at a spatial resolution of 5′ by 5′, distinguishing 26 crop classes, and blue versus green water. Besides further developments of global scale hydrological models emphasis should be put on strategic decision support systems. To get the complex message across there is a need for user-friendly tools that enable decision makers to efficiently visualise and assess the impact of possible intervention techniques. In this respect focus should be on water allocation tools such as the Water Evaluation and Planning (WEAP) tool developed at the Stockholm Environment Institute. De Condappa *et al.* (2009) applied this tool for example in the Volta basin. Serious gaming is another emerging field that should be taken into account.

2.2.1.1.3 Global Water-Food-Climate Datasets

Huge amounts of public domain datasets are available nowadays, but there is a need to integrate and standardise these data for application in water-food-climate studies. Remote sensing could play a major role here as more and more remote sensing data becomes publicly available. A dedicated data portal for water-food-climate studies should be developed that integrates climate (change) data, physical conditions (land use, soil), water consumption by agriculture, reservoirs from a variety of sources. A key gap in data availability is a consistent real time dataset of consumptive use of water by agriculture (evapotranspiration). Algorithms are available that derive evapotranspiration and water productivity from satellites (Zwart *et al.*, 2010) but more work is required in this field. In addition there is a great need for gauge corrected precipitation datasets.

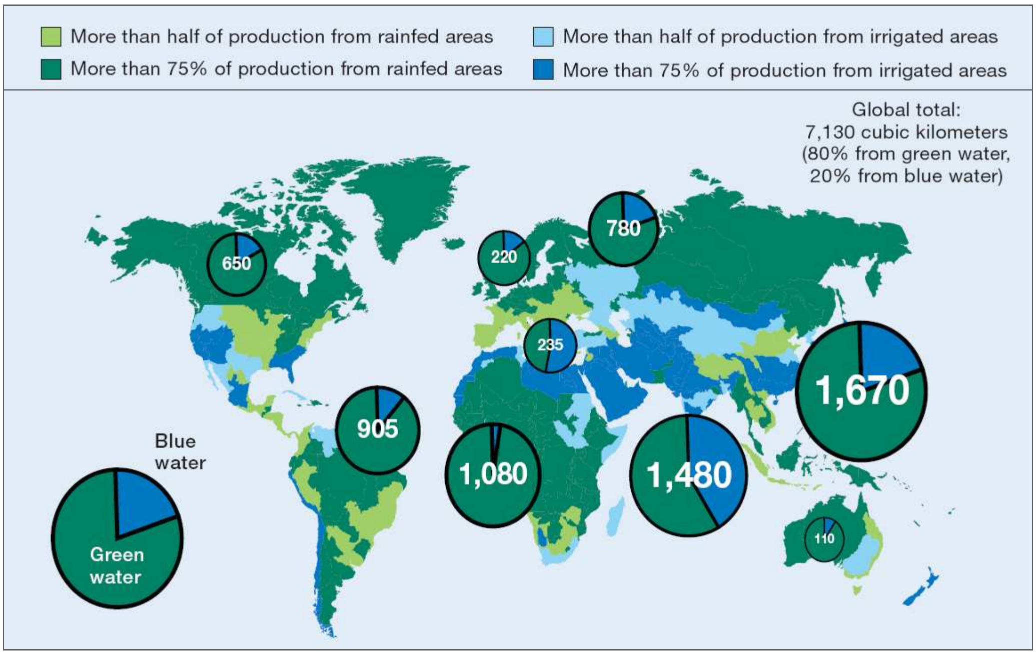

Figure 3: Food crop evapotranspiration from rain and irrigation (Source: Molden, 2007).

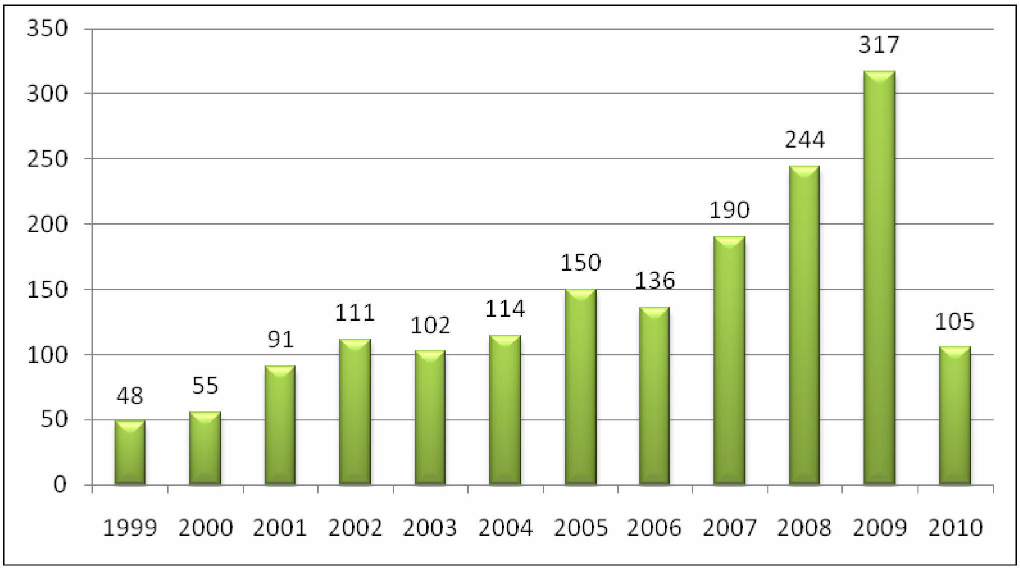

Figure 4: Number of publications (Scopus) using search words: water+food+climate.

2.2.1.2 Science-Policy Interplay

The science-policy interplay on water and food can be considered as very high. In fact the first global assessment on food supply and demand was published by Thomas Robert Malthus in 1798, who famously predicted that short-term gains in living standards would inevitably be undermined as human population growth outstripped food production. However, the more recent scenario studies at the global level indicate that applying innovative methods and policies the potential of agriculture is large enough to meet present and future food demand through increased productivity (Molden, 2007). An optimistic rainfed scenario for example assumes significant progress in upgrading rainfed systems while relying on minimal increases in irrigated production, by reaching 80% of the maximum obtainable yield. This leads to an average increase of yields from 2.7 metric tons per hectare in 2000 to 4.5 in 2050 (1% annual growth). With no expansion of irrigated area, the total cropped area would have to increase by only 7%, compared with 24% from 1961 to 2000, to keep pace with rising demand for agricultural commodities. The same study indicated also that focusing only on rainfed areas carries considerable risks. If adoption rates of improved technologies are low and rainfed yield improvements do not materialise, the expansion in rainfed cropped area required to meet rising food demand would be around 53% by 2050. Globally, the land for this is available, but agriculture would then encroach on marginally suitable lands and add to environmental degradation, with more natural ecosystems converted to agriculture (Molden, 2007).

In contrast to this optimistic few, Rost *et al.* (2009) presented, what they claim, one of the first studies focusing on a spatially explicit quantification of water limitations in global crop production and the potential of different water management strategies to upgrade crop growth, under both present and projected future climate conditions. The study indicated that even the most ambitious and large-scale water management efforts on present cropland will not be sufficient to guarantee the food demands of a growing world population. This result is quite in contrast with most other studies (Molden, 2007; WWDR, 2006; WWDR, 2009; Rosegrant *et al.*, 2009). A nice overview of these global assessments studies was published in Science by Rosegrant and Cline (2003).

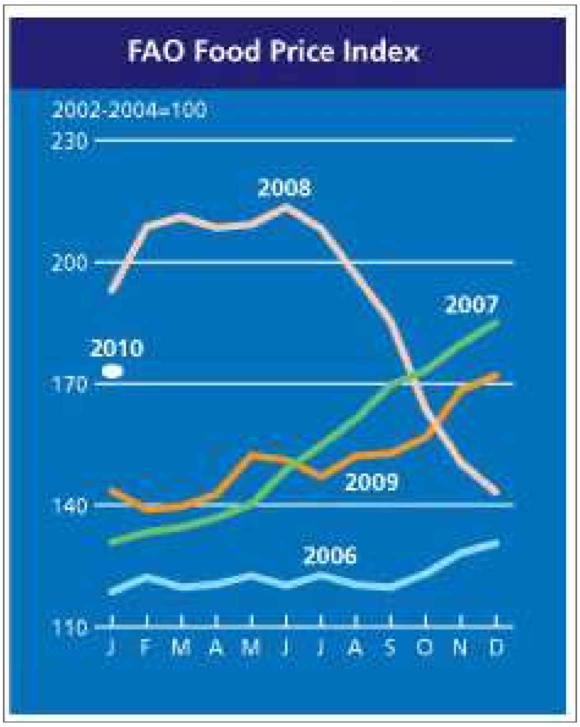

Figure 5: Food Price Index (Source: FAO).

2.2.1.3 Relevance of International Policy Problem

There is sufficient evident that the issue of food security and the linkage to water is an emergent policy problem and is currently moving higher on the policy agenda. The issue will be most likely persistent over the next decade and become even more urgent. This is in still contrast to the expectations of over a decade ago, when food prices dropped and food security appeared to be more a sharing problem rather than a shortage problem.

However, after decades of improvements, the number of undernourished people (in millions) in the world has been rising rapidly since the mid 1990s (FAO, 2009). Development aid has seen an interesting trend. In the wake of the global food crisis of 1973–75, large investments in the agriculture sector (including for scientific research, rural roads and irrigation) led to rapid growth in cereal yields and lower cereal prices that, in turn, significantly reduced food insecurity. During those decades, the proportion of Official Development Assistance (ODA, i.e. development aid contributed by donor governments) devoted to agriculture was also relatively high. During the 1990s and the current decade, however, the number of undernourished has risen, despite the benefit of slower population growth, and the proportion of undernourished increased in 2008 (Figure 6 and Figure 7). In the same period, the proportion of ODA devoted to agriculture declined substantially; in 2007, after adjusting for inflation, the level of ODA was 37 percent lower than in 1988.

The FAO report "The State of Food Insecurity in the World: Economic crises – impacts and lessons learned" provides a convincing statement on the relevance of water and food on the international policy problem (FAO, 2009). The fact that undernourishment was increasing even before the food and economic crises, suggests that present solutions are insufficient. To eradicate food insecurity improved governance at the international, national and local levels are essential.

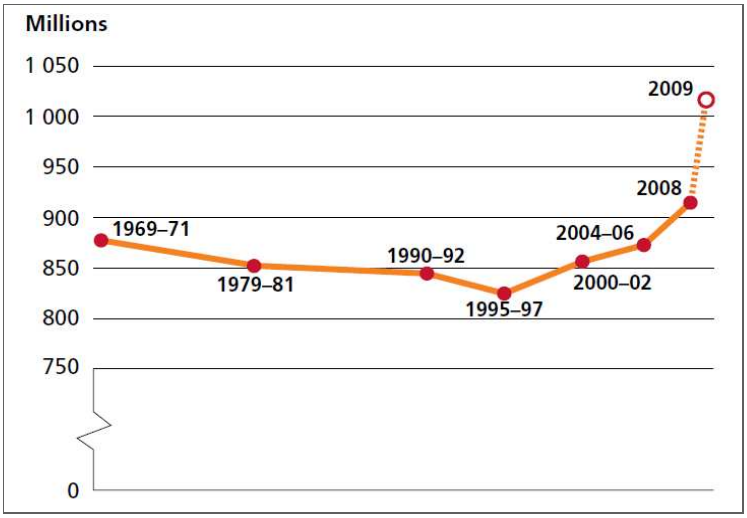

Figure 6: Absolute numbers of undernourished humans in the world. (Source: FAO, 2009).

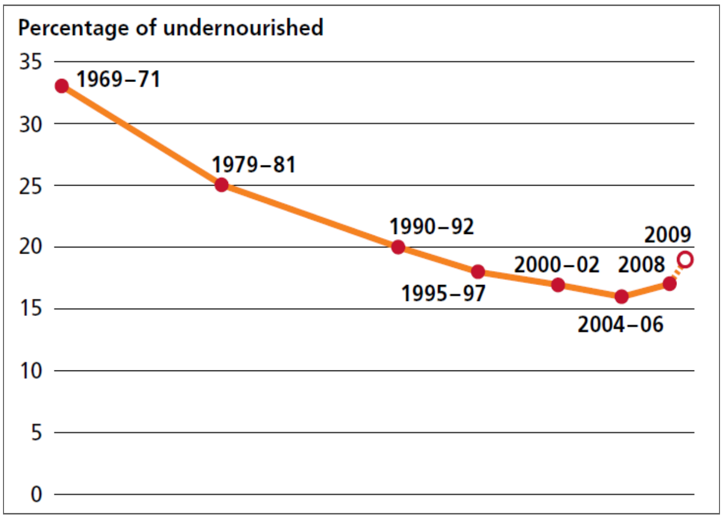

Figure 7: Number of undernourished humans in the world as a percentage of the global population. (Source: FAO, 2009).

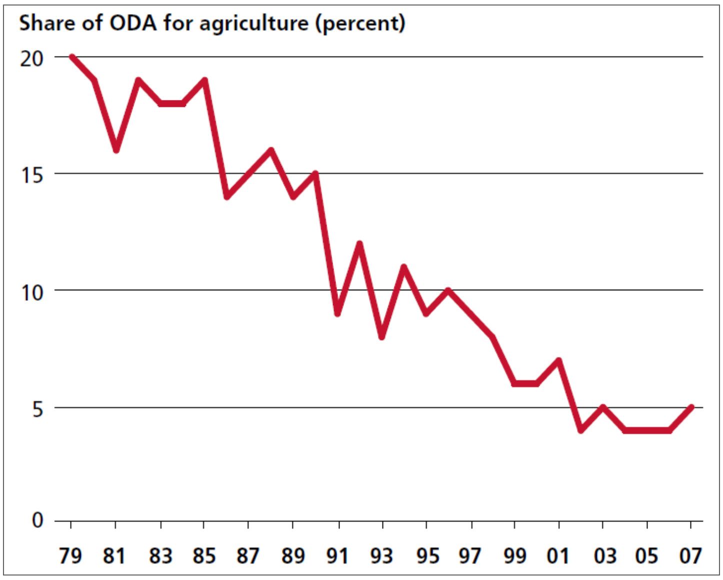

Figure 8: Official Development Assistance (ODA) as share for agriculture.

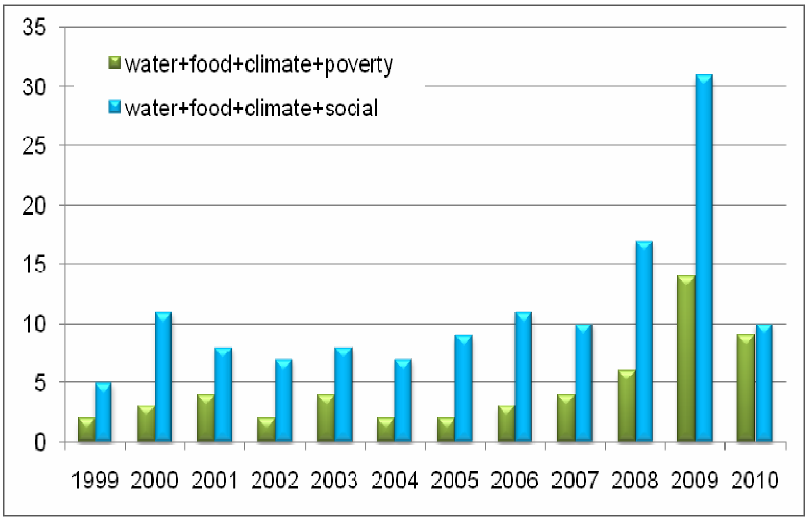

Figure 9: Number of publications (Scopus) is using search terms as indicated.

2.2.1.4 Suitability of the Programme to be Implemented in the German Scientific Community

There is great potential for the German scientific community as German scientists have contributed considerably in the development of a global water-food-climate framework. One of the first being active in this field is the University of Kassel with their WaterGap approach (Alcomo *et al.*, 2003; Döll *et al.*, 2003). At the institute for physical geography of the University of Frankfurt a number of scientists are very active in this field as well. A global crop water model (Siebert & Doll, 2010), a global data set of monthly irrigated and rainfed crop areas (MIRCA) was developed (Portmann, 2010) and a global dataset with irrigated areas (Siebert *et al.*, 2002). The work at the Potsdam Institute for Climate Impact Research is also relevant (Lotze-Campen *et al.*, 2005) and on the interface of global food demand, productivity growth and the scarcity of land and water resources. Recently, the Potsdam Institute for Climate Impact Research has also started an emerging programme on global water-food analysis using quantitative tools (Hoff, 2010).

2.2.2 Application Area 2: Water and Food in Africa from a Global Perspective

Workshop “Future trends and research needs in water management”; 2nd to 4th February 2010 Osnabrück, Germany

Water and Food in Africa from a Global Perspective

The global framework to be developed requires a strong emphasis on Africa, where the most potentials but at the same time the biggest threats to food and water security occur now and in the future. The framework for Africa will be developed simultaneously with the global model but specific emphasis will be put on the economics of extensive foreign investments in land, closing yield-gaps and management aspects.

Box 4: Application Area 2 of the workshop “Future trends and research needs in water management”.

Main conclusions:

- Africa holds important potential for global food production by 2050
- Water is a limiting production factor, mainly due to unreliability of rains
- Large scale irrigation development is unlikely to take off soon
- Localised water harvesting strategies are needed
- A detailed predictive model is needed to assess the potential of different water harvesting techniques at sub-country level that takes landscape position into account
- The German research community is in a good position to contribute to this topic.

Box 5: Major workshop conclusions in Application Area 2.

2.2.2.1 Link Global Perspective to Food Production in Africa: Relevance of International Problem

The importance of Africa for global food production concerns two issues. First, food production in Africa has not kept pace with the global increase in agricultural productivity. Africa remains a net-importer of food and malnourishment on the continent is an important international concern.

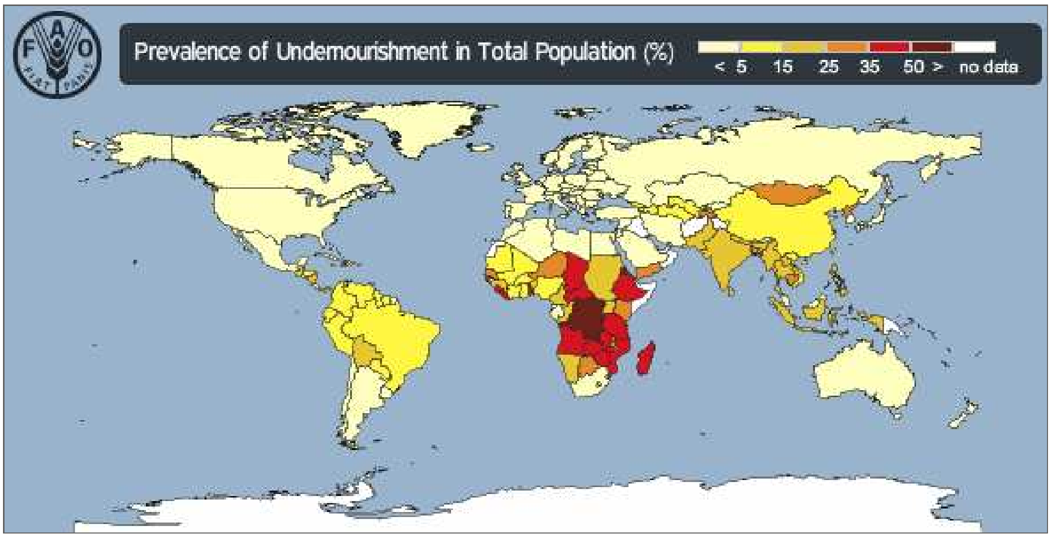

Figure 10: Distribution of malnourishment (2004-2006). (Source: FAO, 2009).

As can be seen from Figure 10, malnourishment is very prominent throughout Africa be it that the more severe cases are often directly linked to conflict and not necessarily to droughts or other agricultural limitations. The willingness of the international community to provide food aid is large but tends to have negative effects on the competiveness of African farmers. Africa, it seems, has sufficient agricultural resources to feed itself.

'If agriculture has a final frontier, it is Africa. After agriculture transformations in Asia and Latin America since the 1960s, Africa remains the one place where the farming potential has barely been scratched. African agriculture has less irrigation, less fertiliser use, less soil and seed research, less mechanisation, less rural financing, fewer paved farm-to-market roads than any other farming region in the world.'

Roger Thurow, Wall Street Journal, 27 May 2008

From a global perspective it is interesting to note that Africa holds significant promise with respect to raising world food production. Most of Asia is under stress and the slight decrease in agricultural land over the past decade is mainly due to Asian urbanisation edging out agriculture. Agricultural expansion in Latin America tends to come at the cost of important biodiversity strongholds such as Amazonia and the Pantanal. Eastern Europe and Central Asia have potential but the issues here are mainly institutional. Africa seems to be the most obvious place to significantly boost international food production. Experts agree that the main way to expand Africa's food production is through taking more land into production. (Hoogeveen *et al.*, in preparation). Only where population pressure is high, such as in Machakos, Kenya or the Mosi Plateau in Burkina Faso, does intensification of agriculture, such as through irrigation, become feasible.

2.2.2.2 Gaps in Scientific Knowledge

The scientific literature on water and food production in Africa is dominated by the so-called "green&blue water" discussion (Hoff, 2010). "Green" water is water that is held under tension in the upper parts of the pedosphere that, from a practical point of view, can only be accessed productively by plants. "Blue" water is water under zero or positive pressure that can be pumped up and stored (groundwater, lakes, rivers). It is widely recognised that >95% of the food produced in Africa is grown under rainfed conditions (Alcamo *et al.*, 2007). This stands in contrast to Asia, where the green revolution depended for a large part on the development and intensification of large scale irrigation infrastructure.

Water is clearly a limiting production factor in Africa but its exact role is not always clear in a complex production system where nutrients, labour availability, and access to market and cash also play important roles. The lack of reliability in rainfall patterns greatly reduces the expected returns on investments in agro-chemicals, seeds, and soil management. See, for example, Sultan *et al.* (2005) for an interesting study for West Africa of the role of in-season dry spells on crop productivity. The question then becomes how temporary water scarcity can be overcome.

Opinions differ on the exact role that irrigation may play in Africa. Based on FAO figures, it is estimated that the irrigated surface in sub-Saharan Africa will have to increase with over 50% by 2050, but the total will still be a mere 7 million hectares of the 377 million hectares world wide (Hoogeveen *et al.*, in preparation). Total irrigation potential is estimated at 40 million hectares. Water productivity in irrigated schemes in Africa tends to be relatively low (Faulkner et al., 2008). There are several reasons why irrigation development in Africa lags behind Asia and other parts of the world. First, there are simply not many large alluvial plains fed by large rivers. Second, state-based governance is weak, reducing the chances at large scale irrigation development. Finally, infrastructure costs are relatively high due to lack of both human resources as well as supporting infrastructure. It is unlikely that there will be a fast turn-around and that irrigation in sub-Saharan Africa will really take off in the near future.

The only alternative is to increase the productivity of "green water". Until now, most of these studies are at a macro level and do not take local specifics into account. The latter are needed in order to move from generic ideas to policies and investments. There are literally thousands of localised detailed agronomic studies concerning water of a specific crop on a specific soil in a specific management setting, etc. There are, however, no synthesising studies that bring together this substantial knowledge base and translate it into regionalised insights in production potentials and water management options.

The main missing link in our knowledge is that between the large scale models and general observations and the detailed localised agronomic knowledge.

In this context, the agronomic knowledge should be interpreted as broadly as possible and should not only include all biotic and a-biotic resources but also the socio-economic context. Especially the role of markets and labour productivity are important in this respect.

From the present perspective it is probably more important to note that hydrological process knowledge is still lacking to improve water harvesting techniques. There are many ways in which water can be harvested and green water productivity can be improved. A very narrow definition of water harvesting, limiting this technique to pure in situ water use, (Hoff *et al.*, 2010), is probably too exclusive. When water is temporarily stored on-farm in small reservoirs or underground, this can still be an important part of improving green water productivity (Savenije, 2000). The more important criteria would be investment costs and "light" governance.

Hydrological process knowledge is essential to target the correct technique for the correct region and for the correct landscape position (Winmeijer & Andriesse, 1993). For example, interception is normally an important part of the water balance in semi-arid environments but has received little scientific attention (De Groen & Savenije, 2006). Improving in situ water would have to address interception, as well as other often neglected losses such as unproductive soil evaporation. The potential of collecting surface water depends largely on slope, rainstorm and soil surface characteristics, yet we do not have the necessary information to map out what can be done where (Van De Giesen *et al.*, 2004). In parallel to the global modelling effort, a more detailed effort is needed for Africa in order to be able to assess the real potential of green water and water harvesting.

The literature count did not show any specific trends on sub-topics such as "Africa + Irrigation". Perhaps the main conclusion is that the overall count is relatively low given the importance of the topic, thereby indicating that there is still ample room for more scientific output.

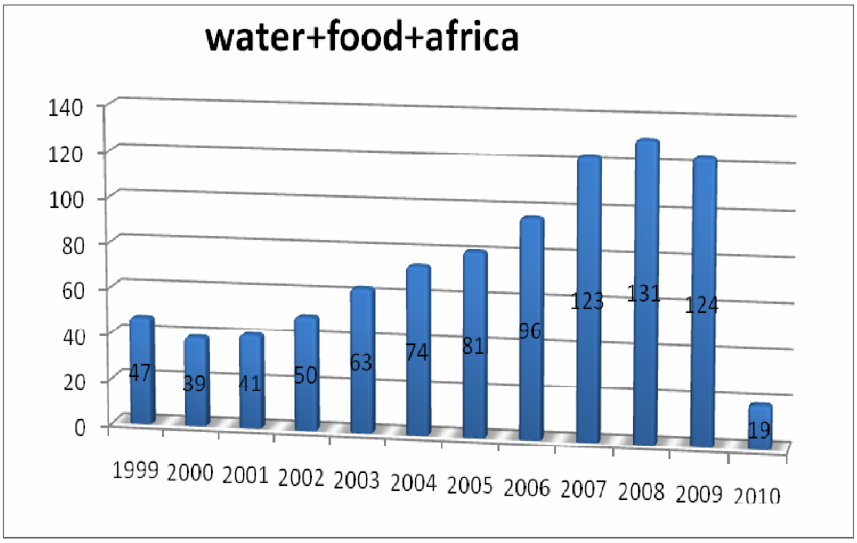

Figure 11: Number of publications (Scopus) is using search terms as indicated.

2.2.2.3 Role of Scientific Research in Support of Policy

Investments will need to be made to boost Africa's food production. There are major international initiatives, such as IFAD's "Advancing African Agriculture", which mainly focus on traditional agronomical solutions. The role of water receives generally little attention, with the important exception of the Challenge Program Water for Food of the CGIAR. Even a substantial research investment by BMBF would not solve Africa's food production problems over night but this particular niche would have relatively good leverage.

The international community is trying to build a "Green Revolution for Africa". The original Green Revolution in Asia was to an important extent based on a parallel "Blue Revolution" consisting of massive investments in irrigation infrastructure. In Africa, such a "Blue Revolution" is needed as well but will most likely not take the form of massive irrigation investments. A one-size-fits-all water management approach can not be expected to yield good results.

National governments, international programmes, donors (Germany, EU, WB, …) would profit from regionalised knowledge on optimal water management options. Such research would help agencies to answer the following question:

- **Where is large scale irrigation development feasible?**
- **Where is supplementary irrigation feasible (design & economics)?**
- **Where are field level measures preferred and what form should they take?**

The current generation of relatively coarse and global models will not be sufficient because they can not go beyond generalities.

2.2.2.4 Role of German research

Germany has extensive experience with respect to agronomical research throughout Africa, for example through GTZ sponsored programmes. The strong involvement over the years in Africa by DAAD is reflected in its programmes in, among others, Stuttgart, Bonn, Hohenheim, and Goettingen. This research experience provides the basis of the localised knowledge that is needed to improve water productivity in Africa. What is needed is to contextualise the existing knowledge in the framework of continental scale integrated modelling.

Germany is host to the Global Water System Project, which has strong ties with the water (productivity) modelling community. There are strong global modelling groups (Alcamo, Doell) that can provide the large scale methodologies, data management techniques, etc.

BMBF's GLOWA Program, with especially the Impetus & GLOWA Volta projects, has produced a generation of young German scientists who have first hand insight in water and food in Africa. There is also ample experience with integrated approaches from other projects, such as CuveWater at ISOE, and BIOTA. Overall, Germany has the integrative research experience needed to perform the proposed research.

A BMBF programme/project on water and food in Africa would (should) bring together these different communities.

2.2.3 Application Area 3: Water and Food in Big Cities from a Global Perspective

Workshop “Future trends and research needs in water management”; 2nd to 4th February 2010 Osnabrück, Germany

Water and Food in Big Cities from a Global Perspective

Big cities are by enlarge ignored in current global water-food studies. However, urban agriculture, waste water irrigation, urban livestock, domestic water competition and food trade are key in global water-food analysis. For a few mega-cities these aspects will be studied and included in the global water and food framework. Based on these pilot cities all big cities will be implemented in the framework. Scenario analysis will indicate in which direction water-food issues will develop and what decisions could be taken for sustainable development.

Box 6: Application Area 3 of the workshop “Future trends and research needs in water management”.

Main conclusions

- Given the continuing urbanisation, the extractive nature of the city economy in terms of water, food and energy, needs to be changed.
- The theme “Water and Food in Urban Areas” can only be addressed meaningfully in the broader framework of the complete water-food-energy nexus.
- Transition management will have to be an important research theme.

Box 7: Major workshop conclusions in Application Area 3.

This section is for an important part based on the earlier report by Engelbert Schramm, Rutger de Graaf and Thomas Kluge produced for the February workshop.

2.2.3.1 Link Global Perspective to Water and Food in Urban Areas

Since October 2008, more than 50% of the world population lives in cities and this percentage will continue to increase for the next 50 years. Already in 2030, the global urban population will be over 5 billion. As a collateral development, the global rural population will decrease from 2020 onwards. The traditional asymmetrical relation between urban and rural areas may have to be revised thoroughly.

Some of the oldest existing irrigation systems are urban systems (Sanaa, Jericho, Aleppo). However, in the present socio-economic setting, food production in urban areas is seen as marginal at best (peri-urban agricultural). At the same time, we see a certain industrialisation of agricultural and, especially, horticultural production that could easily be accommodated in an urban setting. Still, the theme water and food in cities would most productively be addressed if seen in the context of the urban hydrological cycle (including drinking water and waste water) and energy production and distribution (heat/cold storage, solar energy collection, evaporative cooling).

The global water-food-energy nexus is especially complex in urbanised areas. From a water perspective, cities have parasitic relation to the surrounding rural areas. Drinking water is extracted from outside and, once polluted, dumped outside. Energy production does not typically take place within cities and results in extra pressures on water resources (reservoirs, heating). A transition is needed in which cities will take more care of their own water, energy and food.

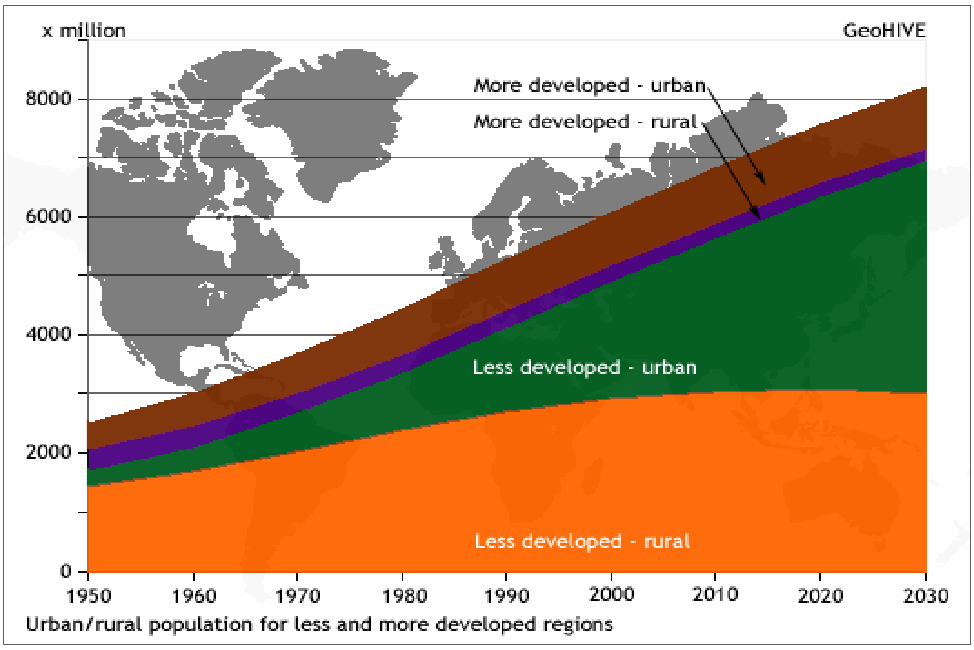

Figure 12: Development of urbanisation.
(Source: http://www.geohive.com, referenced to Population Division, UN: World Population Prospects: The 2004 Revision, and World Urbanisation Prospects: The 2003 Revision.)

From a technical point of view, it is possible to analyse the town-hinterland relations in order to find out what kind of ecological backpack is brought into town along with food and what kind of dependencies exist between a town and the water supplies of its hinterland. In a similar way virtual water could be taken into consideration in order to examine where successful water saving is sabotaged by externalising production steps.

Since the 19th century, there has been a debate on using nutrients transported by sewage water. At the moment, it seems that the stated role of nutrient cycling from wastewater or sewage sludge is over-estimated. Recent dissertations carried out at the Universities Hannover and Darmstadt prove that the efficiency of nutrient cycling lower than expected. Only a change in boundary conditions caused by the predicted shortage of *P* or *K* minerals or by high energy prizes (fixation of *N* via Haber/Bosch process) will promote to process urban sewage water in such a way that it will be reused as a risk free and good practicable manure in future agricultural and urban gardening systems (De Graaf *et al.*, 2007; Schramm, 2008).

According to Niemczynowicz (1999) the future challenges within urban water management will be to organise cross-sectoral stakeholder cooperation in order to introduce innovative water technologies, management systems and institutional arrangements. These systems should be able to meet the multiple objectives of equity, environmental integrity and economic efficiency, and at the same time achieve a high level of water services.

The scientific literature on water and food production in urban areas is dominated by the discussion on re-use of waste water, especially in the developing world. As such, there is a strong focus on areas under severe water stress (Middle East, North Africa, South-West USA).

Possible further inter linkages between the urban and agricultural systems have hardly been regarded. In the long run, the integration of organic waste (biodegradable section of waste) in urban sewage treatment plants might lead to synergies and more efficiency in the processes (Kluge *et al.*, 2009). Processed wastewater and improved types of sludge might be used in urban gardening. Irrigation with wastewater will decrease overall water shortage and stabilise the urban ecosystems needed for urban climate adaptation.

2.2.3.2 Gaps in Scientific Knowledge

Hydrologically speaking, urban areas are blind spots. Many traditional measurement protocols are not valid in cities. Rain has to be measured away from buildings, which is impossible in a city. We have good models of sewage systems, but lack data on their functioning, especially during critical rainstorms. Reliable data about evaporation and groundwater seepage are scarce due to lack of monitoring. Urban agglomerations are becoming a more and more important part of a watershed. Hydrological process knowledge has to be collected in urban watersheds. The role of urban areas in the water cycle is regarded as an interesting research theme (cf. Holt & Pullen 2007). The diagram below presents a representation of the complete urban water cycle (De Graaf, 2009)

The implementation of innovative solutions is hindered by institutional barriers and technical lock ins. On the other hand, environmental and hygienic laws and recommendations are the drivers of innovations in urban water technology. To successfully implement new concepts and new technologies, they must be embedded in the socio economic system, that is: user practices, perceptions, guidelines, legal frameworks and markets. Mouritz (1996) argued that the design of future water infrastructure should be developed by integrated planning and management of land, water and other resources. Also Van Rooy *et al.* (1998) stated that water is a part of our environment and that water policies interact with urban planning policies. In addition, each development should aim to improve the functions of natural water system to maximise local environmental and economic benefits (Ellis, 1995).

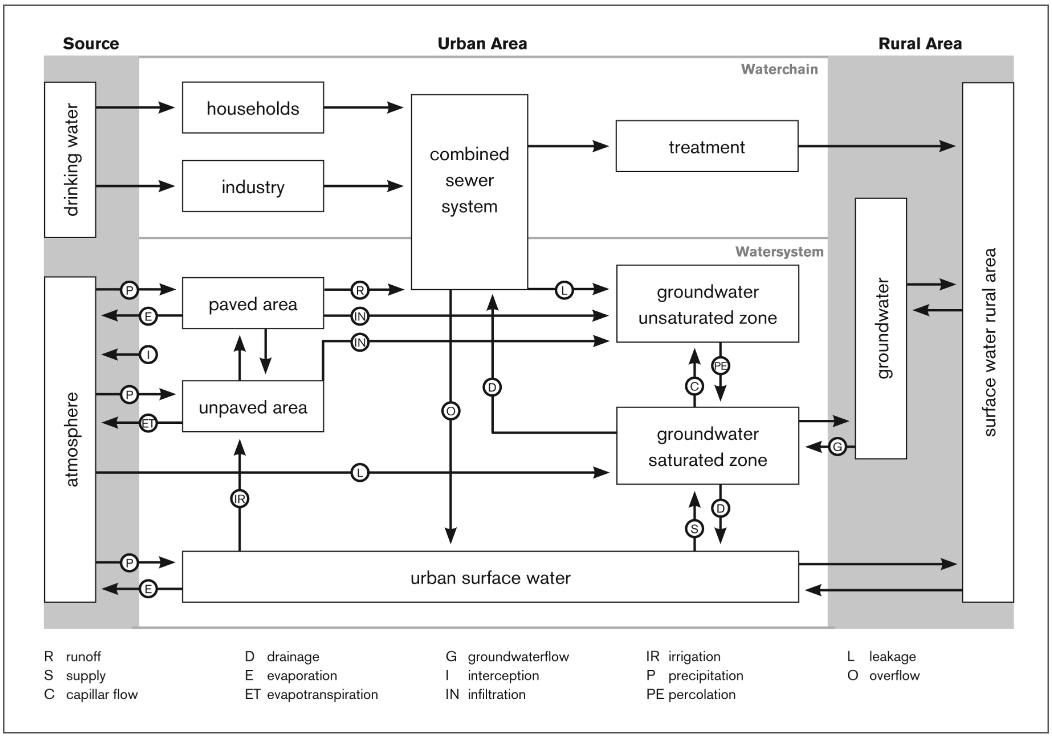

Figure 13: Urban water cycle.

In the last 150 years there was a division of labour: This has led to isolated optimisations of each of the following systems: Water supply, sewage water disposal, energy supply, waste disposal and urban gardening. Institutional fragmentation has resulted in functional silos in which part of the system is optimised in isolation of other system components. This has led to a suboptimal overall system performance. Technical optimisation of a component of a large technical system may prevent system innovation. Moreover, it may lead to a technical and institutional lock in. Different organisations are responsible for the interrelated components of urban water systems. Fragmented accountability frameworks of urban water organisations leave limited room for action that diverges from statutory responsibilities. Institutional objectives of urban water management organisations are focused on performing prescribed task within legal frameworks. There is no defined responsibility for the overall urban water system. Reward mechanisms are based on fulfilling procedures, within the boundaries of projected costs and projected timeframes (De Graaf 2009).

Recently, a transition oriented literature has emerged that focuses on how to move towards more sustainable environments. Researchers have become increasingly interested in the ongoing transformation of urban water systems. Changes in the urban water management approach can be classified as paradigm shifts, transitions, regime shifts or transformations (Van Der Brugge & Rotmans, 2006; Brown & Clarke, 2007; SWITCH, 2006). The effects of climate change and developments such as urbanisation, the European Water Framework Directive, and societal concerns about the sustainability of urban water system force the sector to adapt. Stakeholders are becoming more involved in urban water management. Urban water systems have to fulfil an increasing number of functions and are influenced by various conflicting values. Thus, the connection with urban planning and development, that is the process through which spatial functions are determined and values are negotiated, is increasingly important. Concepts such as Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID) and Integrated Urban Water Management (IUWM) reflect approaches in which the connection with urban planning and social amenity is highlighted. Most approaches stress the necessity of an integrated system approach that includes the total urban water cycle.

The main missing links in our knowledge concern:

- **Understanding of the urban hydrological cycle**
- **Overview of available and expected technologies**
- **Transition management, stakeholder involvement**

Although one needs to differentiate between cities in the developed and developing world, and between existing urban areas and new developments, these three missing links are relevant throughout.

The components of the urban water system are interrelated and should research in an **integrated** fashion. Wastewater, stormwater, drinking water supply, groundwater and surface water should be studied and managed by using an integrative approach. An important element in this approach is the use of an integrated, cross-sectoral, multidisciplinary institutional framework (e.g. Butler & Parkinson 1997; Niemczynowicz, 1999; Geldof & Stahre, 2006). Some authors consider the urban water system as a complex adaptive system (Geldof & Stahre, 2006) or sociotechnical system (Brown & Clarke, 2007) rather than a technical system. Not only the metabolism with the urban hinterland but also the urban water system as such can be seen as a social-ecological system.

2.2.3.3 Role of Scientific Research in Support of Policy

According to an international expert discussion "Sustainable Urban Water Infrastructure – Possibilities of Adaptation and Transformation" (2008 in Berlin, Germany, organised by the NetWORKS group) there will be major changes in urban water management during the next 20 years. Approaches towards a differentiated way of coping with water (e.g. supply with process water, separated treatment of black and grey water) are no longer only subject of pilot projects. Researchers from Australia, China, France, Germany, Israel, the Netherlands, Sweden, Switzerland, and the USA have confirmed that the central question of a purposeful design of the transition to a new infrastructure system is of high policy relevance. One of the challenges will be a management for this transition process allowing a “good governance” for the municipalities and their utilities (Felmeden *et al.*, 2009; Kluge *et al.*, 2007).

Besides the obvious links to the practice of city planning and development, there is an interesting additional policy angle with respect to the “battle for the minds”. Many cities in the developed world, but especially in Europe, see themselves faced with the fact that they have become less attractive to higher income citizens and have become the default dwelling place for the more “resources challenged” part of the population. It is recognised that cities will have to re-invent themselves and that they need to compete for the better brains that will produce the added value in the service and knowledge industries. A sustainable, healthy, and attractive environment are an important and explicit part of strategies by almost all European cities.

This desire to become “attractive” is now translated into actions and investments that are based on feel good ideas from the underbelly (more trees, green roofs, waterfronts, …). This research would ensure that these expensive PR campaigns will actually lead to more sustainable cities.

Outside the developed world, megacities with extensive non-planned city parts (slums and favelas) are often the rule. The development, operation and maintenance of water provisions and sanitation services for such huge agglomerations and the related impact of urban development on its natural resources, need special management concepts and tools. Varis (2006) summarises the situation and future prospects of seven rapidly expanding megacities in various parts of the developing world: Jakarta, Johannesburg, São Paulo, Mexico City, Riyadh, Istanbul and Singapore. He concludes that megacities are dramatic cases of urbanisation and water-related challenges. A main constraint is that even though the provision of water for various sectors is quite important, water is not the only aspect of infrastructure development needed in megacities. Transportation, energy and housing should also be developed (cf. above "inter linkages"). Research on transitions towards more sustainable cities would directly support Germany's development aid efforts.

2.2.3.4 Role of German Research

Germany has a very strong water sector when it comes to drinking water and waste water treatment ("*Siedlungswasserwirtschaft*"). To a large extent this experience has followed an "engineering" approach. In addition, Germany is traditionally strong with respect to urban and regional planning. In Germany, there have been noteworthy innovations in the past two decades in the field of alternative water supply and sewage disposal technology. To date, however, these innovations have only been implemented in a few, small-scale pilot projects. The specific experiences gathered through experimental housing and urban development projects do not, however, provide sufficient basis to draw general conclusions or do not indicate that the innovations are applicable in current terms for implementation on a larger scale and combined with existing facilities and networks.

Water and food in urban areas is clearly a field that is in its inception phase. Countries like Australia and Japan are somewhat ahead but mainly focus on their specific problems hazards and droughts). There is room for a strong programme with a clear international outlook.

The real innovation that is needed is to lift urban water management above a narrowly defined sector approach. Linking water to all relevant aspects of urban development is a logical step. Sufficient institutes exist in Germany that can bring a more integrative approach to the table, building on previous experience with BMBF and EU research projects (GLOWA Program, UfZ, Uni-Osnabrueck, ISOE). With the mix of traditional technical strength, innovative integrators and a strong home market, a BMBF project in this field would (should) produce innovative strategies for the cities of the future.

2.2.4 Application Area 4: Water and Food in Asia from a Global Perspective

Workshop "Future trends and research needs in water management"; 2nd to 4th February 2010 Osnabrück, Germany

Water and Food in South-East Asia from a Global Perspective

Water and food interrelationships are extremely high in South-East Asia. High population concentrations, large dependency on erratic rainfall, huge irrigation schemes, vulnerable to sea-level rise, and complex water competition issues make the area extremely important from a global as well as regional perspective. The region will be studied in a multi-disciplinary way, with a strong focus on risk and vulnerability issues. The study will be developed simultaneously with the global water-food framework to ensure linkages between and within the region and the global scale.

Box 8: Application Area 4 of the workshop "Future trends and research needs in water management".

Major Conclusions

Gaps in scientific knowledge

- Intensive large scale irrigation is a key characteristic of Asian agriculture. There is a scientific gap in methods to assess the dependence of these systems on melt water, groundwater or local runoff.
- There is a gap in knowledge about the regionalisation and timing of the effects of extreme weather events (droughts and floods) on crop failure.
- Climate-water-food hotspots in Asia are the Indus Basin Irrigation System and the Northern China plains, where water is scarce, demand is high, population is rising rapidly and hydro-political situation is tense. Adaptation research should focus on selected hotspots.
- The human dimension in water-food-climate research is weakly developed.

Science-policy interplay

- There is a continuously debate whether large scale irrigation is also benefiting the poorest of the poor. By integrating the physical and human sciences integrated analysis can be performed. Regions in Asia can serve as a case for this.
- Developments in Asia are often seen as a blue-print for Africa. The regional component of the global framework could serve to support decision making.

Relevance of international policy problem

- Himalayas are seen at the water tower for over two billion of people. Climate change will change melting of snow and glaciers. There is however no consensus to what extent this will influence food production in the region.
- Countries in Asia are running out of natural resources, including land to produce food. These countries are now heavily investing in Africa, including purchasing or leasin land for agriculture. Impact for Africa and Asia will remain high on the international policy agenda.

German Scientific community

- Germany has a couple of global initiatives with Asian components focusing on human dimensions of global change and water-food. At the same time are some universities active in Asia on developing physically based approaches on the same topics. Combining these two approaches would have the potential to create a very strong long-lasting collaboration on Asian research in Germany.

Box 9: Major workshop conclusions in Application Area 4.

2.2.4.1 Gaps in Scientific Knowledge and Potential to Achieve Scientific Breakthroughs

During the last half of the 20th century tremendous advances have been achieved in terms of agricultural production in Asia (Pinstrup-Andersen, 2004). At the same time, agriculture remains for livelihoods in Asia a key component and hence, of poverty and food insecurity in the region. It is projected that the proportion of food insecure people in Southeast Asia will decrease from 12% in the period 1997-99 to essentially zero in 2030 (Craswell, 2005). Other key issues for agriculture in the region will be the challenge of meeting the increasing demand for animal protein as incomes rise in Asia, and the accelerated pace of globalisation and its implications for trade.

The physiography of most countries in Southeast Asia put additional challenges in terms of food and water in context to global change. Most countries comprise large hilly or mountainous areas and floodplains where water accumulates during the monsoon season. The floodplains are the high-potential areas, and especially important are the irrigated alluvial deltas that are intensively cultivated to rice (Craswell, 2000). Nevertheless, it is mainly in the extensive marginal hilly areas that one finds farms with low productivity and low incomes, with serious problems of food insecurity at the household level. It is in the high-potential area that the intensified production of staple grains has met demand and kept grain prices low for the urban poor. Continued high productivity from such areas is essential not only to provide food for urban populations, but also to reduce, at the national level, the pressure to intensify agriculture on marginal lands.

These high-potential floodplains are however prone to natural disasters (Lebel *et al.*, 2009). Over the past thirty years the number and impacts of flood disasters has continued to increase across Asia (ABI, 2005; Dutta & Herath 2004). This has occurred despite vastly improved abilities to monitor, warn and describe floods. In the region this in part reflects growth in absolute numbers of people living in flood-prone areas and higher values of infrastructure at risk (Nicholls *et al.*, 2007); thus, around urbanising regions new flood-sensitive settlements and land-uses are expanding into low-lying wetlands and rice paddy landscapes.

Important in the food-water-global change discussion in South-East Asia is the uncertainty in the so-called Water Tower function of the Himalayas. The admitted error in the 4th Assessment Report of the IPCC claimed:

> *"Glaciers in the Himalaya are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate."*

However, a recent article in Science (Immerzeel, Van Beek, & Bierkens, 2010) provides a much more balanced, based on scientific approaches, conclusion. The authors' results show that Asia's water towers are threatened by climate change, but that the effects of climate change on water availability and food security in Asia differ substantially among basins and cannot be generalised. The effects in the Indus and Brahmaputra basins are likely to be severe owing to the large population and the high dependence on irrigated agriculture and meltwater. In the Yellow River, climate change may even yield a positive effect as the dependence on meltwater is low and a projected increased upstream precipitation, when retained in reservoirs, would enhance water availability for irrigated agriculture and food security (

Figure 14).

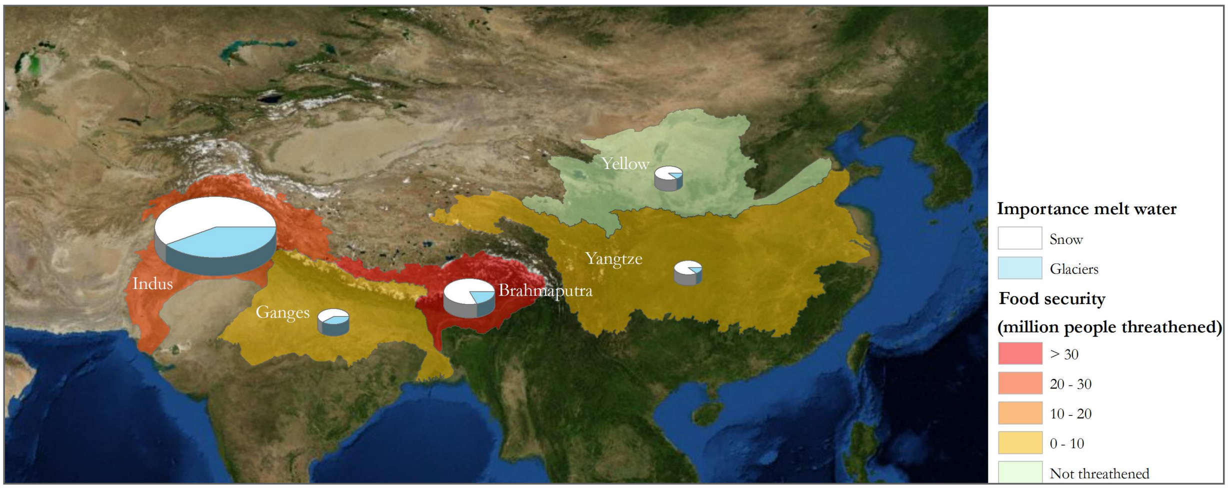

Figure 14: Dependence on meltwater and rainwater for food production (Source: Immerzeel *et al.*, 2010).

Asia is also prone to water shortage, despite the relatively high precipitation amounts some areas experience (Eriyagama *et al.*, 2009). Per capita availability of mean annual river discharge allows areas of both 'climate-driven' and 'population-driven' water scarcity to be identified (Falkenmark *et al.*, 2007). A typical example of these two different water scarcities is the fact that due to India's higher population density, its water scarcity may be interpreted as 'population-driven' as opposed to 'climate-driven' water scarcity in countries like. Thailand, Pakistan and (Southeastern) China.

Based on the above several scientific gaps can be distinguished that vary in location and theme:

On a regional scale it is important to further quantify in space and time how the intensively irrigated agricultural systems such as the Indus Basin Irrigation System (IBIS), the Gangetic plains and the Northern China plains depend on either snow or glacial melt water from the mountains, groundwater or local runoff. At the regional scale it is also important to further develop methods to quantify the effects of extreme events such as drought and flooding on crop failure.

Key focus areas could be identified as hotspots where research on adaptation to climate change of irrigated agriculture could focus on. The IBIS and the Northern China plains are obvious choices. The Indus basin is hydro politically very sensitive given the tension between Pakistan and India, the Indus water treaty of 1960, over 140,000 km^2 of irrigated area, high population pressure and the high dependence on melt water and thus high susceptibility to climate change. On the Northern China plains the majority of grains are produced to feed over a billion Chinese. The plains are dry and unsustainable use of groundwater resources for irrigation results sharp drops in groundwater levels.

Adaptation measures should focus on modernising irrigation systems and improving water productivity (e.g. more crop per drop), optimising water allocation as most irrigations systems are fed by reservoir systems, development of less water consuming crops or crops that can survive short-term flooding and economic incentives to save water.

2.2.4.2 Science-Policy Interplay

It is clear that water-food in the context of global change has been changing rapidly over the last decades and will continue in the future in Asia. Especially the linkage with global issues is in this highly populated continent has a very high international science-policy interplay. Approximately 70% of the world's irrigated land is in Asia, where it accounts for almost 35% of cultivated land (Molden *et al.*, 2007). The concept of virtual water is especially relevant for this region, and should be worked out further focusing on inter-annual as well as year-to-year variation.

In the densely populated areas, such as the rice growing areas of Asia, irrigated agriculture declines due to urban expansion. Also, it is a continuously debate whether irrigation helps to poverty alleviate poverty or whether irrigation contributes mainly to the somewhat better offs (Hussain & Hanjra, 2003).

Finally, at the science-policy interplay the debate on large-scale infrastructure, such as reservoirs, irrigation, and basin-transfer is very relevant for Asia (WCD, 2000). However, since developments in Asia are often seen as a blue-print for development in Africa, there is a clear need for a retrospective analysis with a clear window to the future.

2.2.4.3 Relevance of International Policy Problem

For Asia there are two major issues that are high on the international agenda in the context of water-food and global change. The first one is the role of climate change and water for food issues regarding melting snow and glaciers in the Himalayas. Especially the discussion on mitigation versus adaptation is an emerging topic of the area.

Second international policy problem is the high population growth of Asia and the big demand on resources, including food, on particular Africa. It is well known that various countries in Asia, especially China and India, have an aggressive policy on obtained land in Africa to secure their food demand in the future. It is clear that a global approach is needed to study the impact of these actions on Asia as well as Africa.

2.2.4.4 Suitability of the Programme to be Implemented in the German Scientific Community

The German research community has a broad interest in Asia. Some of the more global initiatives located in Germany (specifically Bonn) have often specific projects in Asia. A big step forward was the so called "Central Asia Water Initiative" (Berlin Process). In 2008 Germany's Federal Foreign Minister announced the launch of the Central Asia Water Initiative at the Berlin water conference "Water Unites". The initiative was an offer from the German Government to the Central Asian countries to provide support in water management and make water the subject of greater cross-border cooperation.

From a more academic perspective some universities have developed strong research in Asia (e.g. ZEF and Jena). Large research projects such as Brahmatwinn are often focused towards the more physical components of the water-food-climate interactions. Combining these more physically based approaches with the earlier mentioned human dimensions would have the potential to create a very strong long-lasting collaboration on Asian research in Germany.

3 Theme Cluster 2: Water related Risks, Vulnerability, and Adaptive Capacities under Conditions of Uncertainty

Authors: Niklas Gebert, Jörn Birkmann and Christian Kuhlicke

Executive Summary

Vulnerability can be defined as

> *"[…] the dynamic feature of an element at risk (population, community, region, state, infrastructure, environment etc.) that determines the expected damage/harm resulting from a given hazardous event. Vulnerability changes continuously over time and is driven by political, institutional, physical, social, economic and environmental factors […][.]"* (Thywissen, 2006)

Although multi-level and causal vulnerability frameworks exist, in the context of natural and particularly water-related hazards, vulnerability research up-to date has achieved little progress to model the vulnerability of complex systems and to develop best practices for their governance. "Vulnerability" is not explicitly mentioned but reflected in the concept of Integrated Water Resources Management (IWRM) by emphasising the need to understand the political, technical, social, environmental, and economic drivers and their links when dealing with water related problems. Even though the international disaster risk policy community promotes and calls for strategic and systematic approaches to reducing vulnerabilities and risks to hazards, the impact perspective still dominates over the vulnerability perspective. The increasing water related disaster risks due to climate change requires among other things the further advancement of IWRM, particularly in terms of the role of modelling and governing the vulnerability of complex systems. Because a lot of challenges exist with regard to the assessment and management of vulnerability of complex systems, priorities for areas of future research are:

(a) Risk governance and institutional vulnerability,

(b) Risk and adaptation related to urban dynamics and

(c) Vulnerability of coupled Critical Infrastructures.

Risk governance research puts emphasis on understanding cross-scale, cross-sectoral and cross-border governance and institutional structures that regulate social-ecological systems and influence the configuration of water related disaster risks. With such analysis a "good risk governance" conceptual framework and monitoring system can be developed that includes quality criteria and respective indicators to facilitate and monitor disaster risk reduction in the context of IWRM.

Since risk and adaptive governance is a cross-cutting research domain it also applies to urban adaptation and dynamics, and coupled critical infrastructure vulnerability research. Both topics play a major role in vulnerability science; because vulnerability related trends in urbanisation (shrinking in developed and rapidly growing in developing countries) and the increasing dependency of the population on critical infrastructure services (e.g. water and

electricity supply) pose extraordinary challenges with regard to govern adaptation and disaster risk reduction. In order to develop resilience-based frameworks for the governance of cities and critical infrastructure it is necessary to explore solutions and best practices how to deal with the uncertainties of climate change and the scientific shortcomings associated with downscaling the consequences of climate change. Hence, it is necessary to investigate on how to link research lines of urban and Critical Infrastructures studies with natural science approaches of climate change downscaling. In doing so, it is necessary to understand the institutional challenges in applying science-based climate change and vulnerability information for the development of adaptation options for urban agglomerations and Critical Infrastructures.

In this context, more urban related vulnerability research is needed that identifies the various trends of urban vulnerability dynamics and in particular the underlying processes and structures that shape the emergence of vulnerability and its patterns of rapidly evolving mega-cities and fast shrinking urban areas.

Regarding critical infrastructure related vulnerability research a key challenge is the development of a conceptual framework and respective empirical research lines that capture the vulnerability of coupled systems and interdependencies between Critical Infrastructures (CIS), society and environment. Such a framework and empirical research should also consider the influences of increasing deregulation and privatisation of CIS services on the overall vulnerability and adaptive capacity of CIS and society. Additionally, the development of protection standards for resilient CIS and coupled systems of CIS, society and environment is needed that also provide guidance for governing the processes of critical infrastructure innovations (e.g. general digitalisation of CIS, or “smart grids” in electric power supply).

3.1 Introduction

The report has been written within the overall frame of vulnerability and disaster risk research (see Birkmann, 2006; Bohle, 2001; Cardona, 2004; Cutter, Boruff & Shirley, 2003; Wisner, Blaikie, Cannon & davis, 2004) and in the light of increasing climate variability creating the likelihood of increased water related disaster risk as well as long-term changes of coupled social-ecological systems (Linton,). Also for the international water research community the need has been recognised to focus more on understanding the social, economic and environmental and institutional drivers of water related risks and vulnerabilities in order to develop solutions to proactively deal with the growing challenges of climate change impacts.

After a first screening of relevant future research topics in this field of water related hazard and disaster risk research an in-depth analysis by distinguished scientists has been conducted during the workshop “*Future trends and research needs in water management*” (2nd to 4th February 2010 and hosted by UFS, University of Osnabrück), and highlighted the following application areas as priority topics for future water related vulnerability and risk research:

- Risk Governance and Institutional Vulnerability (by UNU-EHS);
- Risk and adaptation related to urban dynamics (by UFZ);
- Vulnerability of coupled systems particularly linked to critical and supply infrastructures systems (by UNU-EHS).

The major goal of the report is to present an overview of each application area and to provide a first outline of key research questions and potential research projects in that particular research area. In this regard the analysis of each application is structured according to the following criteria:

1. an introduction into the topic;
2. a state of the art analysis of the respective topic;
3. research gaps and future research needs;
4. outline of a potential research project.

Further evaluation of each application area and proposed research agenda using the following sub-criteria:

- Gaps in scientific knowledge and potential to achieve scientific breakthroughs
- Relevance of international policy problem
- Suitability of the programme to be implemented in the German Scientific community (critical stock of available expertise, potential to strengthen an emerging research community)
- Science-policy interplay link to relevant stakeholders, efficiency and effectiveness of implementation, potential of a programme to have real impact.
- Nature of implementation of the programme (minimum duration of the programme, kind of programme, resource requirements)

Before dealing with the in-depth analysis of each application area, the following section will provide an overview of the three selected areas within the broader context of applied vulnerability and risk research in the field of water related hazards and particularly coping and adaptation strategies to climate change.

3.2 Assessing and Managing the Vulnerability of Complex Systems: Challenges for Water related Vulnerability Research

Even if greenhouse gas concentrations stabilise in the coming years, impacts from climate change are unavoidable due to inertia related to bio-physical processes in the atmospheric, oceans and other global systems (dangerous climate change) (Lenton *et al.*, 2007). The resulting impacts include increasing water stress in many regions, more extreme weather events and consequently water related disasters that already today pose the highest threat to human development (

Figure 15).

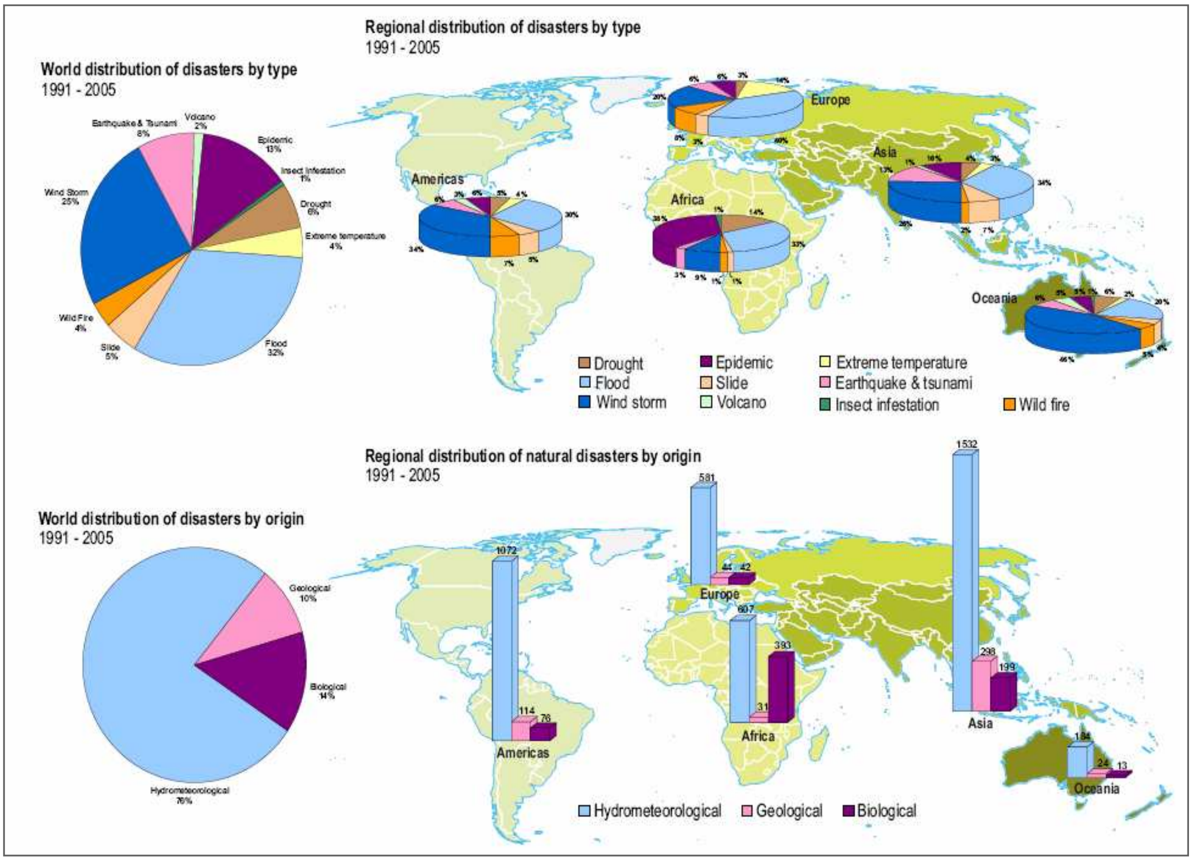

Figure 15: Regional distribution of disasters by type 1991-2005 (ISDR, 2007).

With the heading of chapter 1 “Getting out of the box – linking water to decisions for sustainable development” of the recently published World Water Development Report 2009 it is recognised that:

> *“[…] Important decisions affecting water management are made outside the water sector and are driven by external, largely unpredictable drivers – demography, climate change, the global economy, changing societal values and norms, technological innovation, laws and customs, and financial markets. Many of these external drivers are dynamic and changing at a faster pace.”* (UN-WATER, 2009, p. xix)

In this regard the concept of Integrated Water Resources Management (IWRM) emphasises the need to focus on political, technical, social, environmental, and economic drivers and solutions when dealing with water related problems. This is also particularly relevant when dealing with climate variability and change water related stressors and disaster risk. However, the idea to consider all aspects is still a major challenge, especially due to the various links between the drivers (cf. UN-WATER, 2009, p. 74 and p. 242).

To be able to deal with the gap between water management challenges (under conditions of uncertainty and complexity in the context of climate change) and their manageability the

Regional and National Research Program Network on IWRM [1] (IWRM, 2009) poses the following questions:

- How to develop an understanding of cause-effects relationships of future impacts on the water system?
- How to develop inter-disciplinary tools and methods for IWRM (physical, ecological and socio-economic processes)?
- How could climate change affect water- and ecosystems?

In order to understand and manage the cause-effect relationships of current and future impacts on the water system and develop adaptation strategies scientists and policy makers underline the need to examine the various vulnerabilities of systems exposed to water related hazards in a changing climate, rather than focusing solely on impacts (cf. Kelly & Kelly, Adger; IPCC, 2001; UN, 2005). In this regard the final declaration of the World Conference on Disaster Reduction, "Hyogo Framework for Action 2005–2015", underlines the need to promote strategic and systematic approaches to reducing vulnerabilities and risks to hazards (United Nations, 2005, preamble). The declaration points out that

> *"[…] the starting point for reducing disaster risk and for promoting a culture of disaster resilience lies in the knowledge of the hazards and the physical, social, economic and environmental vulnerabilities to disasters that most societies face, and of the ways in which hazards and vulnerabilities are changing in the short and long term, followed by action taken on the basis of that knowledge."* (UN, 2005)

The different authors and policy documents call for improved risk-based approaches, however, the development of respective information systems and management approaches (WWDR, 2009; DAS, 2008; UN, 2005) often does not sufficiently capture the multi-faceted nature of vulnerability. Where the term vulnerability is used it is mostly related to exposure only or to the definition of unfavourable conditions, in which exposed populations in developing countries are living, such as poverty, income insecurity and low education. Thus most approaches link vulnerability to general factors of underdevelopment. The limited understanding of what vulnerability is all about in a wider context is mainly due to the fact that the impact perspective dominates over the vulnerability perspective. According to Vogel and O'Brien (2004) the impact perspective has traditionally been used to emphasise on the potential consequences of a particular event, while in contrast the vulnerability perspective draws attention to those factors – of human or environmental origin – that, together or separately, account for the vulnerability of the receptor, for example a community or ecosystem, leading to disasters (Vogel and O'Brien, 2004, p. 2). Thereby vulnerability can be defined as:

> *"[…] the dynamic feature of an element at risk (population, community, region, state, infrastructure, environment etc.) that determines the expected damage/harm resulting from a given hazardous event. Vulnerability changes continuously over time and is driven by political, institutional, physical, social, economic and environmental factors […] [.]"* (Thywissen, 2006)

The definition underlines indirectly the need to focus also on "the vulnerability of complex systems". In this context cross-scale interactions and processes between different thematic

1 Regional and National Research Program Network on IWRM website: `http://www.iwrm-net.eu/spip.php?rubrique`

dimensions (social, economic, environmental) play a major role. These interactions have also been taken into consideration by vulnerability frameworks that particularly stress the social-ecological perspective, such as the framework described by Turner II *et al.* (2003). Practical example of such coupling processes can be seen in coastal communities affected by water related hazards, as well as in the various interdependencies of societies in developed countries and their dependency on critical infrastructure services (Birkmann & Krings, 2008; Kaplan et al., 2009).

Although multi-level and causal vulnerability frameworks exist, vulnerability research up-to date has failed so far to model *the vulnerability of complex systems* and its dynamics. Also the ICSU Science Plan for Integrated Research on Disaster Risk (ICSU, 2008) stresses the fact that the dynamics of vulnerabilities are not well understood and calls for research on the dynamic modelling of vulnerability. At the same time, future research is required to provide guidance on how to manage *the vulnerability of complex systems* within multi-stakeholder environments, particularly taking into account different stakeholders, such as state-, private sector-, and civil society organisations. To improve the quality of decision making and to provide integrative management strategies research on water related risk and adaptive governance is needed that also considers multi-level and cross-boundary decision making in the context of natural hazards (ICSU, 2008; IHDP, 2009).

These two perspectives on future research challenges, namely assessing and managing the vulnerability of complex systems and its dynamics, served as a basis to specify future research needs and to deduce three application areas for an in-depth analysis:

The application area "**Risk governance and institutional vulnerability**" (section 3.3.1) is linked to the issue of root causes of vulnerability and addresses the challenges of managing *the vulnerability of complex systems*. Thus, issues of governance are also addressed when developing future research topics related to urban and critical infrastructure vulnerability.

> *"[Risk governance] looks at the complex web of actors, rules, conventions, processes and mechanisms concerned with how relevant information on the causal structure of vulnerability in hierarchical and complex social-ecological relationships is collected, analysed and communicated and how management decisions are taken […][.]"* (Renn, 2008; IRGC, 2005; Biermann, 2007)

Thus, risk governance can be regarded as how adaptation is conducted, where adaptation is defined as

> *"[…] an adjustment in the ecological, social or economic system in response to observed or expected changes in climate stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities […][.]"* (IPPC, 2001)

This definition of adaptation has similarities with the understanding of adaptation in the frame of IWRM. IWRM also stresses the need to focus on various adaptation aspects and drivers, such as very much fits political, technical, social, environmental, and economic drivers of adaptation when dealing with water related problems (UN-WATER, 2009).

The other two application areas **"Risk and adaptation related to urban dynamics"** (section 3.3.2) and **"Vulnerability of coupled critical and supply infrastructures systems"** (section 3.3.3) are chosen, because they represent two very important topics of the vulnerability of complex systems that the world faces: How do trends in urbanisation and de-urbanisation and the increasing dependency of the world society on Critical

Infrastructures interact with unknown and known changing environmental conditions such as climatic change that lead to increased water related disasters and long-term stress?

3.3 Application Areas

3.3.1 Application Area 1: Risk Governance and Institutional Vulnerability

Research on disasters due to hazards of natural origin and particularly water related hasards primarily focuses on understanding the patterns of risk outcomes, by e.g. modelling flood inundation sones or assessing the exposure and vulnerable conditions of people (Handmer, 1999). Natural sciences, geography, sociology, Engineering and spatial planning are the disciplines predominantly represented in recent vulnerability research. Although, the identification and assessment of vulnerabilities and risks of exposed elements is still an important research domain, another perspective on risk and vulnerability is currently raising attention of international scholars, i.e. the focus on regulatory aspects of risk and vulnerability. In this regard special attention is given to formal and informal institutions, rules and actors that regulate risk and vulnerability. The institutional dimension of disaster risk and vulnerability has been discussed for some years; however, only little research has been done in the field of vulnerability and risk governance and regulation. This is also a result of the fact that political and also legal scientists are underrepresented in natural disaster vulnerability research. Risk governance as a recently evolving research field has the potential for putting an advanced perspective on the institutional dimension of natural disaster risk, vulnerability, adaptation and resilience. Currently, this research discipline is prominently represented by the German sociologist Ortwin Renn (2008), whose scientific work on conceptualising risk governance has significantly shaped the International Risk Governance Council's (IRGC) research and policy agenda (see IRGC, 2005). Although Renn and the International Risk Governance Council focus primarily on risk related to technical hazards and economic losses the methodologies and phases of the assessment can also be useful for enhancing the identification and assessment of institutional vulnerabilities within the context of disaster risk reduction linked to natural hazards and water related hazards in particular. Risk governance as the target and challenge to cope with increasing certain and uncertain water related disaster risk in the context of climate change gains much importance in the international policy dialogue since it addresses multi-level and cross-sectoral regulatory challenges by governmental and non-governmental stakeholders to reduce risks in complex societal and political environments (see Pahl-Wostl & Toonen, 2009; MIDIR, 2008; IHDP, 2009; ICSU, 2008).

3.3.1.1 Scopus Analysis

To assess the current state of development in this field of research, a bibliometric analysis of publications using SCOPUS database has been conducted for the time period of the past 10 years. Different combinations of key words in the context of the overall topic were inputted into the search engine. The combination of the different key words (Figure 16) was chosen to explore the trend on the role of governance and institutions in vulnerability science. The results show for each combination of terms the number of publication in peer reviewed journals in the search space of 'articles', 'proceedings papers', 'reviews', and 'editorial material' that included the 'search terms" in abstract, titles or key-words.

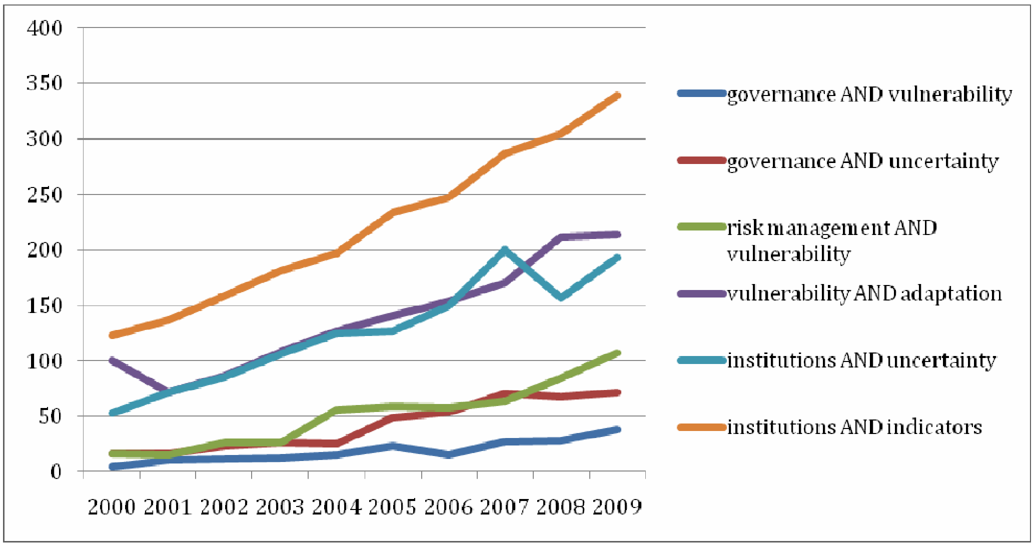

Figure 16: Number of publications regarding governance related to institutions, vulnerability and uncertainty in peer-reviewed journals.

The results show for all combinations of key words that number of publications using these key words has increased by 100%. Particularly, the topics of "governance and vulnerability", "governance and uncertainty" have not been addressed as much in publications as the others, but since 2000 there is significant increase showing growing interest in this young research field. Interestingly, the topic of "institutions and indicators" has been addressed more often in scientific publications then the others issues examined within the analysis. The implications of these trends will be outlines in the following sections.

3.3.1.2 Institutional Vulnerability and Limitations of Applied Adaptive Capacity Research

This section aims at providing an overview about the recent trends in the research domains of institutional vulnerability and adaptive capacity. Thereby, short-comings of the concept and assessment of adaptive capacity will be outlined to lead over to argue about the importance to focus on risk governance and regulation.

Institutional vulnerability can be defined as the institutional fabric of state organisation; private sector and civil society that influences the likelihood of damage or harm as well as the unusual difficulties in recovery of elements at risk (e.g. citizens, economy, infrastructures, environmental services) that are impacted by a hazard event (water related hazard). Institutional vulnerability changes continuously over time and is driven by political, legal, social, cultural, economic and environmental factors at multiple scales. Thus, institutional vulnerability research does focus on the role of institutions in avoiding or creating risks and vulnerabilities of exposed elements. Institutions are defined as rules or norms which define the roles, rights and responsibility of actors (Young, 2002). Households, communities, firms or states, can represent such organisational entities that encompass various institutions and rule systems, which can be formal rules (e.g. legislation) or informal rule systems (social norms or customs) (Lebel, Nikitina, Kotov & Manuta, 2006). These institutions tempt to reduce uncertainty of interaction between different stakeholders (North, 2005).

Whereas the sciences of *new institutional economics* is dealing with the analysis of the impact of institutions on the economy (North, 2005), institutional vulnerability research linked to disasters due to hazards of natural origin such as water related hazards in particular, focuses on the role of institutions that shape vulnerability and risk to natural hazards and climate change – including adaptation processes. The institutional dimension of vulnerability is well reflected by international research scholars. E.g. Adger *et al.* (2007) recognises that there are many examples where institutions such as social relations, economic structures, values, perceptions, customs, traditions, levels of cognition and those forming formal governance affect the capability of communities to adapt to risks related to climate change (Adger *et al.,* 2007). Wisner *et al.* (2004) addresses in his Pressure and Release Model (PAR) risk creating configurations of institutional setups as root causes of vulnerability. They argue that addressing vulnerability requires solutions that include political change, radical reform of the international economic system, and the development of public policy and regulation to protect rather than exploit people and nature. Special institutional challenges in the current scientific debate on risk and vulnerability arise from anticipated climate change challenges. In this sense climate change and water related stress becomes a risk factor unless the system is able to adjust to the changing conditions and engage in adaptive actions (Lim & Spanger-Siegfried, 2005). Thus, the capacity to adapt is a critical element of adaptation processes. "*It is the vector of resources that represent the asset base from which adaptation actions can be made*" (Adger & Vincent, 2005). There is a growing recognition that vulnerability and the capacity to adapt to climate change are influenced by multiple processes of change at multiple levels and thus is highly differentiated, also within countries (O'Brien & Leichenko, 2000; Turner *et al.*, 2003; Luers, 2005; Leichenko & O'Brien, 2002; Dow *et al.*, 2006; Smit & Wandel, 2006; Ziervogel *et al.*, 2006). E.g. economic consequences of trade liberalisation are likely to have both positive and negative consequences for the overall adaptive capacity of cities and regions (Pelling, 2003; Adger *et al.*, 2007). Furthermore, studies carried out since the IPCC Third Assessment Report (TAR) show that adaptive capacity is not only influenced by economic development, but also by social trends such as urbanisation and factors such as human capital and governance structures (Klein & Smith, 2003; Brooks & Adger, 2005; Naess *et al*., 2005; Tompkins, 2005; Berkhout *et al*., 2006; Eriksen & Kelly, 2007).

A significant short-coming of adaptive capacity research is its missing link to adaptation outcomes. There is some evidence that for assessing adaptive capacity and vulnerability national-level indicators are used by climate change negotiators, practitioners, and decision makers in determining policies and allocating priorities for funding and interventions (Eriksen & Kelly, 2007). However, few studies have been globally comprehensive, and the literature lacks consensus on the usefulness of indicators of generic adaptive capacity and the robustness of the results (Downing *et al.*, 2001; Moss *et al.*, 2001; Yohe & Tol, 2002; Brooks *et al.*, 2005; Haddad, 2005). A comparison of results across five vulnerability assessments shows that the 20 countries ranked 'most vulnerable' show little consistency across studies (Eriksen & Kelly, 2007). Haddad (2005) has shown empirically that the ranking of adaptive capacity of nations is significantly altered when national aspirations are made explicit. He demonstrates that different aspirations (e.g. seeking to maximise the welfare of citizens, to maintain control of citizens, or to reduce the vulnerability of the most vulnerable groups) lead to different weightings of the elements of adaptive capacity, and hence to different rankings of the actual capacity of countries to adapt. It is these uncertainties and thus a major limitation of the concept of adaptive capacities because it emphasises on the resources available for adaptation where no evidence can be found whether these resources of adaptive capacity can predict positive adaptation outcomes (Adger & Vincent, 2005). Here, risk governance science has the potential to develop conceptual foundations and management tools that are capable to better provide guidance for desired adaptation outcomes.

3.3.1.3 Research Needs and Gaps: Risk Governance for Sustainable Disaster Risk Reduction

Since by empirical evidence assessing adaptive capacity cannot predict adaptation outcomes (at least there is a high level of uncertainty, see previous section) new approaches are needed that serve as a valid knowledge bases for taking decisions about adaptation funding priorities and for guiding countries, authorities and other relevant stakeholders to successfully govern vulnerability and risk. Here research on risk governance is a key. The basic difference between adaptive capacity and risk governance research is that the latter focuses more in-depth on policy and decision- making processes that influence those conditions that can alter adaptive capacity and vulnerability (Smit & Wandel, 2006). Thus, instead of focusing solely on the analysis of general adaptive capacities the research on adaptive governance performance advances the research focus, since it enables the development of monitoring systems that evaluate desired risk governance processes and outcomes. The emerging literature on the institutional requirements for adaptation suggests that there is an important role for governments (formal institutions) and respective public policy in facilitating adaptation to climate change (Few *et al.*, 2007). This includes reducing vulnerability of people and infrastructure, providing information on risks for private and public investments and decision-making, and protecting public goods such as habitats, species and culturally important resources (Haddad, Sloan, Snyder & Bell, 2003; Eakin Callaway, 2004; Haddad, 2005; Tompkins & Adger, 2005). However, what this literature often overlooks is the fact that governments face various constraints in implementing risk reduction and adaptation measures, due to the fact that for example water related risks and vulnerabilities do not emerge within administrative units and that large organisations such as governments are complex, with a diversity of stakeholders, capacities and resources. In addition, they operate in the context of uncertainty (e.g. climate change and global change) and ever changing conditions and capabilities of social-ecological systems that are hard to predict. Therefore, risk reduction and adaptation measures developed by governments are not an easy task; rather they are embedded into various uncertainties (MIDIR, 2008). The absence of adaptive management and governance rules, procedures and capacities that cannot deal with non linearity and emergence are one of the major and cross-cutting drivers for vulnerability to water related stress and climate change because it limits sectors and institutions to take advantage of the opportunities or benefits arising from these threats (Adger *et al.*, 2007). Opportunities and benefits that arise from threats are in the first place that governments are set under pressure and consequently urged to accelerate the introduction and facilitation of change.

In their effort to measure governments' and formal institutional performance to manage natural disaster risks Lebel *et al.* (2006) structure "institutionalised capacities and practices" into four clusters, which in their absence and mal-function factor vulnerability and lack of adaptive capacity of formal institutions: Deliberation and empowerment (consensus building), coordination (legislation, policies), implementation (programmes) and evaluation (learning). These aspects can be studied on the systemic, organisational and individual level (MIDIR 2008). Although concepts of governance performance research exists (e.g. sub-national and national level good governance analysis conducted by the World Bank; Kaufmann & Kraay, 2007) and Pahö-Wostl (2009) argue that the analysis of multi-level and complex adaptive governance systems is an underdeveloped area of research and that its analysis has been mostly lacking a multi-disciplinary focus (Young, 2008). Consequently complex adaptive governance related to natural hazards is lacking that accounts for the social-ecological challenges of uncertainty and surprise in the context of climate change. In order to overcome the shortcomings of generic and simplistic approaches but still being able to "*support context sensitive analysis without being case specific*" a diagnostic approach for the analysis of adaptive governance has been called for (Ostrom, 2007; Young, 2008). Thereby, variables of interest can be selected and organised in a nested, multitier framework that is designed to account for a systemic perspective and to "*consider complexity and wealth of interactions, which characterise governance regimes*" (Pahl-Wostl & Toonen, 2009). In the field of disaster risk research with regard to water related creeping and sudden onset hazards the concept of risk governance as an adaptive governance complex can serve as a starting point for the development of further research questions in the domain of applied governance research. Risk governance is of particular importance in situations where there is no single authority to take a binding risk management decision, but where the nature of the risk requires the collaboration of and coordination between a range of different stakeholders.

Here, the development of a set of predefined quality criteria and standards for good risk governance bears the potential to evaluate adaptation and risk management processes and outcomes against benchmarks. But neither adaptation guidelines nor clear normative concepts exist that aim to reduce vulnerabilities and disaster risk. Thus, one of the major research tasks identified is to "*translate the substance and core principles of governance to the context of risk and risk related decision making*" (Gunningham, Grabosky, & Sinclair, 1998) first and then develop criteria and indicators for good risk and adaptive governance. In this context also a framework analysis is needed as well as procedural recommendations on how to use such criteria within actual risk management approaches at different levels. With such concepts, methodologies and indicators at hand, the shortcomings of the static analysis of adaptive capacity can be addressed. Other than adaptive capacity research, risk and adaptive governance research also looks at both the process and outcomes of adaptation: It allows for the assessment and comparison of institutional adaptation performance by evaluating decision-making systems that favour or limit institutional change and adaptation investments by governments and the private sector.

3.3.1.3.1 Theoretical and Conceptual Research Needs for "Good Risk Governance"

The term "good risk governance" is a clearly a normative concept that implies a further operationalisation of what is meant with good risk governance. Conceptual work on risk governance has been carried out internationally and in the German scientific research community. Well known representatives of this research domain are amongst others (see section 3.3.1.4) Ortwin Renn, who is member of the "International Risk Governance Council" (IRGC), and who published amongst others the outstanding monograph "Risk Governance, Coping with Uncertainty in a Complex World". Initial point of emergence is a new concept of risk, which OECD has named "systemic risks" (OECD, 2003). The term implies the embeddedness of any risk to human health and the environment in a larger context of social, financial and economic consequences: "*Systemic risks are at the crossroads between natural events, economic and technological developments, and policy driven actions, all at the domestic and the international level*" (Renn, 2008, p. 5). Thus, handling systemic and non systemic risks are thought to include the following normative cornerstones of risk governance: Hazard identification, risk assessment, concern assessment, tolerability/acceptability judgments (risk evaluation), risk management, and risk communication as a cross-cutting governance task (Renn, 2008). Each of the main components of this risk governance concept includes various sub-components and procedural guidelines developed based on a variety of theories, mainly social science. Although the framework shows substantial scientific progress, the conceptual foundation of risk governance developed by Renn (2008) is applicable mainly to technological risks and has various pitfalls regarding its suitability for natural disaster risk governance. For example, the role of vulnerability assessment is limited to an exposure analysis, although managing *the vulnerability of complex systems* is a key for overall risk reduction. Also processes of exposure manifestation in disaster risk (of natural origin) research are a complex spatial and social-ecological issue that needs to be taken into account when studying risk governance across scales and sectors. In addition the disaster cycle is not recognised in existing risk governance concepts although research programmes such as the IHDP-Integrated Risk Governance Project (IGR) acknowledge the disaster risk cycle in their Science Plan (IHDP-IRG, 2009). The disaster cycle is important for examining institutional vulnerability and risk governance structures, since the different phases outlined in the disaster cycle also imply the involvement of different institutions according to their responsibility.

Overall, the following theoretical, conceptual and empirical research needs in risk and adaptive governance linked to water related hazards can be summarised as key challenges for future research:

Evaluation of existing risk and adaptive governance frameworks regarding their suitability for disaster risk reduction in terms of water related hazards in the context of climate change:

- Development of a “good risk governance” conceptual foundation including core principles, (sub-) components and procedures for water related fast onset and creeping hazards that emphasis on the role of assessing and managing the vulnerability of complex systems in the overall governance process.
- Developing of quality criteria for “good risk governance” with regard to all facets of risk governance: from deliberation and empowerment, to coordination, implementation and evaluation.
- Exploring the challenges regarding governing uncertain hazard impacts and their spatial distribution. In this respect it is also important to examine the imitations of governing water related hazards and vulnerabilities within the existing boarders of administrative structures. Special emphasis should also be given to the need to advance and amend the guidelines for IWRM in this context.
- Understanding the cultural dimension of risk governance in the context of uncertainty

3.3.1.3.2 Criteria and Indicators for “Good Risk Governance”

Indicator development is crucial for the support of policy and institutional analysis, as well as for taking decision on priorities for development assistance and investments aiming at improving good risk governance. The development of criteria and indicators to improve decision making also in disaster risk research is not a totally new topic (see Birkmann, 2006). Economic indicators had already emerged in the early 1940s (Hartmuth, 1998; Reich & Stahmer, 1983). Today, economic indicators such as ‘‘GDP’’ or ‘‘HDI” are broadly used (and politically accepted). In the 1960s and 1970s the development of social indicators was a hot topic in the social sciences (Cutter et al., 2003), which crossed over into the political and social arena during the protest movements in the 1960s in the United States and Western European countries (e.g. Empacher & Wehling, 1999). The development of environmental indicators followed in the 1970s, linked to the establishment of environmental policies. A big impetus for indicator development emerged from the discussions about sustainable development. In this context various approaches to defining and operationalising sustainable development with indicators were undertaken (UNCSD, 1996; Birkmann, 2004).

The development of criteria and indicators that assess governance processes is a quite difficult undertaking due to the complexity of multi-level risk and adaptive governance systems in which abstracting and simplifying governance complexity but developing robust criteria and indicators is the balancing act. There is substantial experience within a similar field of research and application since 1992 (Woods, 2000). The donor institutions such as the World Bank, the International Monetary Fund, the European Bank for Reconstruction and Development, and the Asian Development Bank and donor nations have an interest in assessing the level of governance in countries where they borrow money for economic and administrative development projects (UNDESA, 2007; Kaufmann & Kray, 2007). Thus, the development of good risk governance indicators can benefit from vast experiences with governance evaluation processes and their methodological challenges such as data collection, sampling, validation of proxy variables, and the applicability of results.

Overall, criteria and indicators for good risk governance in terms of water related hazards are implying the following research needs.

- Evaluation of existing criteria and indicators for good governance and risk governance in terms of their performance and transferability to issues related to risk and adaptive governance in the context of water related natural hazards.
- Development of systemic as well as contextual indicators and criteria for “good risk governance”. These indicators and criteria should be applicable at different levels of governance.
- Development of a monitoring system for “good risk and adaptive governance” related to water related hazards and climate change that can be used by different stakeholders.

3.3.1.4 Evaluation of the Application Area

Gaps in Scientific Knowledge and Potential to Achieve Scientific Breakthroughs

Up-to-date considerable research has been conducted related to the development o governance frameworks and indicators aiming at analysing and monitoring democratisation processes in developing countries as well as governance performance related to public participation and service delivery, economic development facilitation and poverty eradication (Kaufmann & Kraay, 2007). But for managing the vulnerability of complex systems, disaster risk and climate change adaptation a risk governance performance related analytical framework and globally comparable indicators and criteria for good risk governance do not exist (e.g. UN/ISDR, UNFCCC). Hence, governance assessment guidelines and indicators are needed that are generic for international comparison but valid enough for country specific assessments.

For the development of good risk governance theoretical and conceptual foundations and respective indicators (acknowledging the disaster cycle) future research needs to focus first on understanding cross-scale and cross-border interactions of the diverse set of regulatory and institutional mechanisms (with different regulatory culture of institutions and governments, sector policies at different scales, from local to global) that either create, intensify or manage the vulnerability of complex systems. This is especially true with regard to conflicts between social, economic and environmental developments and policies. Second, also the problem of developing benchmarks and quality criteria to determine the quality of governance performance in relation to the problem pressure and the overall capacity of a government and governance regime needs to be solved. The potential to achieve scientific breakthroughs is given, since there is tremendous experience (see Scopus analysis, e.g. "governance and indicators") and long history on governance research in neighboring governance research disciplines (e.g. development studies), from which good risk governance research can benefit.

Science-policy Interplay

Since governance research deals with e.g. policy, decision-making and institutional structures the development of policy analysis tools needs to integrate the views and expectations by policy makers in order to generate acceptance of the results. Hence, the development of theory based good risk governance conceptual frameworks and indicators that shall be internationally standardised and utilised by relevant government and non-government organisations requires the involvement of policy makers, such as the disaster risk and climate change adaptation community, from the beginning in the research process.

Relevance of International Policy Problem

Climate change impacts and natural disaster risks are increasing world wide as at the same time trends of exposure and vulnerability intensification is a global phenomena, too. The international climate change and disaster risk policy community is just about to develop monitoring tools for adaptation and disaster risk reduction performance. Therefore, a research project aiming at developing analytical frameworks and monitoring tools for risk and adaptation governance is of high relevance to the current climate change policy community.

Suitability of the Programme to be implemented in the German Scientific Community

Germany bears a great potential to form a multi-disciplinary group of scientists representing the complex nature of the application area. First, just to mention a few, considerable conceptual competence related to (water) governance, indicator research that exists in Germany are for example the Institute of Social Science, University of Stuttgart, where Ortwin Renn leads the sub-directorate of technological and environmental sociology, and a research group of the Institute of Environmental Systems Research, University of Osnabrück, headed by Claudia Pahl-Wostl. Second, social-ecological research competence is concentrated at various research institutes and programmes in Germany, for example the UNU-IHDP Programme based in Bonn and the Institute for social-ecological research based in Frankfurt. Third, there is a great amount of research competence associated with natural disaster risk research, such as the Center for Disaster Management and Risk Reduction Technology (CEDIM), the Department of Geography, University of Bonn (leading an interdisciplinary risk initiative), UNU-EHS and the Potsdam Institute for Climate Impact Research (PIK). Research Programmes with an inter-disciplinary focus on vulnerability and risk research include the Helmholtz-EOS-Programme, RIMAX and the IWAS initiative. Research communities in the field of political and law science in Germany have a long history and various institutes are specialised in environmental policy and law, such as the

University of Hamburg. But their collaboration with interdisciplinary research programmes and institutes in disaster risk research needs to be strengthened.

Overall, the relevant research landscape that exists in Germany as outlined above is very well connected with the international academia and policy system. This is especially true for the University of Stuttgart, Osnabrück, UNU-IHDP, UNU-EHS, CEDIM, Helmholz-EOS and PIK.

3.3.1.5 Research Project Outline

A research project shall focus on the development of an internationally well accepted and theory based conceptual framework for risk and adaptive governance. The development of the conceptual framework for risk and adaptive governance with regard to water related hazards in the context of climate change should be supported by the development of respective criteria and indicators for good risk and adaptive governance in the water sector. In order to be scientifically sound, a case study based research design should be developed that allows for a systematic global comparison of institutional frameworks and structures for risk governance of water related threats by comparing case study specificities that need to be defined during the course of case study selection. Some criteria that are considered as important are: distinct regulatory culture and governance and national government architectures in place (e.g. centralised vs. decentralised systems or government vs. governance regulative cultures), degree of national government and governance capacities to manage water related risks, degree of problem pressures and experience with water related stress, climate and environmental change. With such a diversity of framework conditions that are attributed to states and governments it will be possible to develop a good risk governance framework and respective indicators that allow the integration of place specific contextual factors of governance as well as generic factors.

Since water related risk governance analysis is considered as an important dimension of social-ecological research a trans- and multi-disciplinary research group composed of researchers representing law and policy, economic, political, social, and natural sciences shall be set up. Furthermore, it is important to take into account the perspective of applied research and to develop knowledge that can improve decision-making processes. Consequently also experts from international and national organisations (e.g. OECD, UN-System, and Development Banks) as well as governments should be involved while designing case study research and respective criteria for good risk and adaptive governance.

3.3.2 Application Area 2: Risk and Adaptation Related to Urban Dynamics

This application documents the state-of-the art with regard to water-related natural hazards such as floods, droughts, flash floods, sea-level rise etc. and how they relate to urban dynamics. The document pays particular attention to the interrelation between the natural and the social urban system and highlights the relevance of urbanisation processes and how they might contribute to the emergence of vulnerable conditions.

The relevance of taking a ‘urban perspective’ is given by the sheer number of people living in urban areas and the ongoing unplanned and unregulated rapid urbanisation process. Meanwhile more than half of the earth’s population is classified as living in urban areas (Simon, 2007); a trend which is likely to continue unbrokenly in the next decades. It is expected that in 2025 even two-third of the global population will live in urban areas (Roy, 2009). Consequently, many small and intermediate cities are experiencing rapid growth rates and the number of so called mega cities also increases. It is projected that more than 600 million people will live in 60 mega cities (i.e. cities with more then 5 million inhabitants) in 2015 (Krass, 2007).

However, the trend of rapid urbanisation is not taking place evenly: More than two-third of these cities are located in the so called 'developing' countries in the global south. Particularly these cities are characterised by explosive growth of population, polarising processes leading social fragmentation, capital accumulation and of low economic development at the same time and poor environmental conditions (Roy, 2009). These urbanisation processes are resulting in an increasing exposure of people, buildings and infrastructures to water-related natural hazards. The exposure will most likely be amplified by the negative consequences of climate change as particularly rapidly developing urban areas are vulnerable to the consequence of climate change (IPCC, 2007). However, there are also inner-urban dynamics, such as an increasing population density within specific urban areas and neighbourhoods, social exclusion, inequality and marginalisation resulting in a heightened vulnerability of people and urban systems (e.g. Kraas, 2007).

Yet, it would be to short-sighted to exclusively emphasise the mentioned developments. First, particularly in Europe and Northern America cities are not only fast growing; many cities show processes of decline and shrinkage (e.g. Kabisch, Bernt, & Peter, 2004; Oswalt & Rieniets, 2006). Second, the process of urbanisation also creates benefits and opportunities as, for instance, economic growth may take place and many urban centres are the places of innovation (Simon, 2007). Cities may have considerable resources as well as coping and adaptive capacities to deal with both rapid changes (e.g. flash floods and floods) and creeping changes (droughts or sea-level rise). It is therefore surely no exaggeration to state that cities are in relation to climate change "*one of the most important battlefields, with their higher concentration of population, economic activities and material and energy consumption, as well as offering the opportunity to investigate novel and replicable solutions*" (Roy, 2009, p. 276).

The following paragraphs give an overview about the current state-of-the art knowledge in the area of "Risk and adaptation related to urban dynamics". Therefore it distinguishes in two overarching topics of "urban dynamics, risks and vulnerabilities" as well as "urban adaptation challenges". The report neither goes into definitional debates (although they will be made explicit, if the subject requires it), nor does it deal with each topic in-depth; it rather concentrates on interconnections and general trends on a global scale. If appropriate it will outline regional differences and/or commonalities, which appear as relevant for an overview article on state-of-the-art knowledge in the mentioned area. As outlined in the introduction two topics will be paid particular attention; that is the rapid growth of urban areas as well as the decline and shrinkage of urban areas. It will also be specified which challenges arise when adapting urban areas to global environmental change. The single paragraphs are structured as followed. At the beginning a short and general overview about the topic is given as well as the state-of-the art knowledge and empirical evidence with regard to the topics is presented. In a second step research needs that should be addressed in future research are specified. Finally, the possible configuration of a research project is outlined.

3.3.2.1 Scopus Analysis

To assess the current state of development in this field of research a bibliometric analysis of publications using SCOPUS data base. Different combinations of key words were used to define 'search terms'. The research results include the number of publication in peer reviewed journals in the search space of 'articles', 'proceedings papers', 'reviews', and 'editorial material' that included the 'search terms" in abstract, titles or key-words.

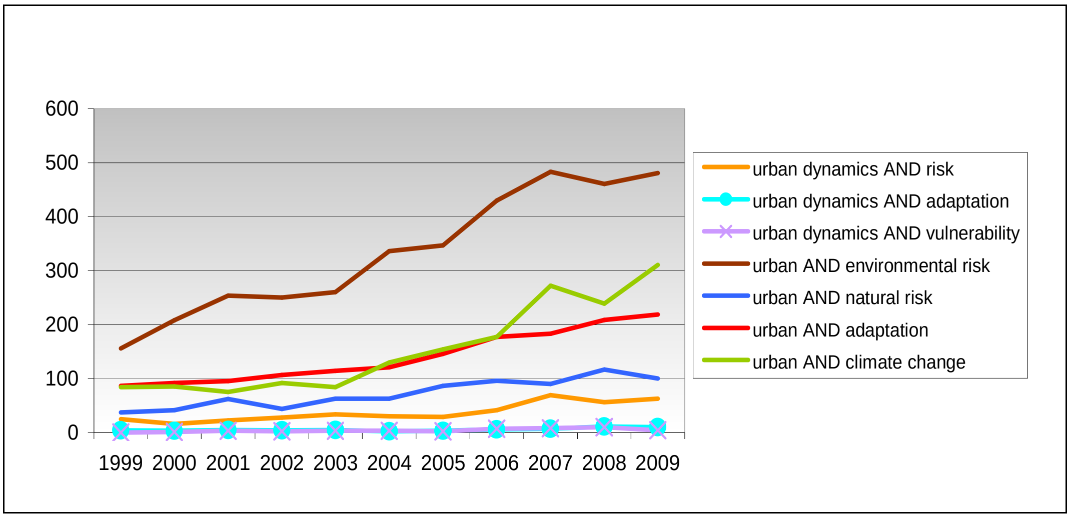

Figure 17: Bibliometric Analysis in the field of Urban Dynamics, Risk and Adaptation.

Highlights that there is a general increase of publication on the terms searched. Particularly, the topics of 'urban AND climate change' as well as "urban AND environmental risk' and 'urban AND adaptation' have gained recognition in recent years. All three topics will be dealt with more in depth below.

3.3.2.2 Urban Dynamics, Risks and Vulnerabilities

In the following the process will be outlined. Which processes contribute to an increase of urban vulnerabilities and risks? There seems to be a large consensus that three distinct processes, which are obviously interlinked and reinforcing each other, contribute to an increase of risks and vulnerabilities in urban areas (Simon, 2007). In the following the process will be outlined.

3.3.2.2.1 The Inter-linkages of Urban Dynamics and Global Change

First, urbanisation processes as such are contribute to environmental changes due to their strong development dynamics, achieving unprecedented high spatial and demographic expansion, concentrations of population, infrastructure, economic power, capital, and decision-making, a high level of energy consumption, burning of fossil fuels as well as an excessive and partially self-energising acceleration of all the mentioned development processes (Kraas, 2007; Simon, 2007; Roy, 2009). Particularly mega agglomeration affect "*global change – understood as global environmental as well as socio-economic and political* *change […] – just as profoundly as global change effects*" mega urban agglomerations (Kraas, 2007, p. 80).

Second, environmental changes affect the urban system, as urban areas are defined by high concentration of population, economic stocks, and infrastructure. Urban areas are in this sense vulnerable to slow moving and rapid approaching environmental changes such as sea-level rise, tropical cyclones, flooding and land-slides, water crisis, and heat and cold waves (Roy, 2009; Simon, 2007). These environmental processes may become even more severe under conditions of global environmental change resulting in an increasing frequency and severity of extreme events, ranging from spring tide to hurricanes and heat-waves; as well as a range of slow onset events or trends, like rising sea levels and increasing atmospheric temperature, with semi-permanent or permanent impacts on the urban system (Simon, 2007, 77). Although real progress has been made in improving state-of-the-art of climate change assessment (Cameron, 2006; Jones, 2000; Le Treut *et al.*, 2007; Walker *et al.*, 2003; Wilby & Harris, 2006), there is still a need for further specifying the impacts of climate change for specific urban areas and to integrate these top-down perspectives also with bottom-up perspectives. There is hence a need to integrate so-called "endpoint" and "contextual" approaches to vulnerabilities (cf. also O'Brien, Eriksen, Nygaard, & Schjolden, 2007). While the first approach follows a top-down perspective and considers which impacts climate change has on urban areas, the latter approach follows a bottom-up perspective and considers how society is vulnerable to and adapts to climate change. The contextual vulnerability approach considers vulnerability as a starting point for the development of adaptation strategies. In this understanding, the emphasis is not so much on the natural system or the exposure of the urban area, but more importantly, on urban processes, structures and developments contributing to the overall urban vulnerability on the one hand and the more specific vulnerability of particular groups on the other hand.

Third, processes, interactions and dynamics within the urban system are contributing to an increase of risks and vulnerabilities of urban areas: While some urban areas are experiencing rapid urbanisation processes; others are experiencing shrinkage and decline.

Urban areas that are defined by rapid urbanisation processes are most often characterised by a general increase of their vulnerability as there are simply more people exposed to hazards (Laukkonen et al., 2009, p. 288). However, by urbanisation processes the urban population becomes also more fragmented and split in different socio-economic groups resulting in the further concentration of vulnerable households on land sites exposed to water-related hazards (Hardoy and Pandiella, 2009). Societal factors influencing the vulnerability of households are, among others, the income of urban dweller (Hamza & Zetter, 1998; Pelling, 2002, p. 291), gender, age, as well as migration status (Bartlett, 2008; Kantor & Nair, 2005; Wehrhahn *et al.*, 2008). Other possible factors contributing to the vulnerability of specific groups are: irregular and casual employment, low and irregular income, size of household, health, education, living standards, social and financial resources (Kantor & Nair, 2005).

Furthermore, informal settlements are vulnerable to water-related hazards as buildings are usually built incrementally over a numbers of years, with materials of diverse origin and quality, and not always following accepted techniques including the missing or insufficient equipment of sanitation infrastructure (Hardoy & Pandiella, 2009). These settlements and its inhabitants are quite often not only exposed to natural hazards, but also to diseases because people are forced to live in neighbourhoods where due to their informal status water supply, sanitation and health service infrastructure does not exist leading to an increase of water and sanitation related disease vectors (Hardoy & Pandiella, 2009, p. 212).

In Europe but also in Northern America the implication of inner-urban dynamics might develop somewhat different. Many old-industrialised cities show processes of population decline. Most notably, aged industrial countries and the post-socialist countries of Eastern Europe show high number of declining cities, which are by some defined as “shrinking cities” (e.g. Kabisch *et al.*, 2004; Oswalt & Rieniets, 2006). These cities are characterised by deindustrialisation, suburbanisation and its urban consequences of vacancy and demolition (Kabisch & Haase, 2009). It is yet an open question which consequences these shrinkage processes may have with regard to vulnerability patterns. However, shrinking urban areas seem to be characterised by a decrease of exposure to water-related natural hazards as less people, economic stocks and increasingly also infrastructure is exposed to environmental hazards and risks. However, with such urban areas new challenges may arise that might reveal new vulnerabilities. First, such cities are most often defined by an aging population, which may be vulnerable to environmental risks and hazards. Second, the loss of population may also challenge the overall financial strength and governmental service provision as well as existing voluntary disasters management systems (e.g. local fire brigades) and other adaptive systems.

3.3.2.2.2 Research needs with regard to urban dynamics, risks and vulnerabilities

In light of the three outlined processes contributing to an increase of risks and vulnerabilities of and in urban areas, future research in this application area should focus in a general sense on the question of how to integrate social scientific and urban studies oriented research lines with rather natural scientific approaches of downscaling and specifying the consequences of climate change.

Particularly in so-called developing countries cities are in many cases rapidly growing resulting in an increasing vulnerability of people, infrastructures and buildings to environmental risks and hazards. In other areas of the world cities are shrinking and declining resulting in vacancy and demolition and a possibly reduced exposure of people and buildings to water-related natural hazards. Currently most of the research on the mentioned urban dynamics is focusing on either rapidly evolving mega-cities and how risk are co-produced through their very growth or on how to adapt to processes of shrinkage and decline. With regard to the latter phenomenon hardly any thorough analysis exists on how shrinkage and the emergence of vulnerable conditions are interlinked. Therefore an overarching approach is necessary, which would allow the comparison of “vulnerability dynamics” of rapidly evolving mega-cities and fast shrinking urban areas. There is a need to better understand the underlying processes and structures and how they influence and define the emergence of vulnerability and its patterns.

A second challenge relates to the integration of so-called “endpoint” and “contextual” approaches to vulnerabilities (cf. also O'Brien *et al.*, 2007). While both approaches to vulnerability are well established in their respective scholarly area, the integration of both is still not yet satisfyingly achieved, particularly not on the level of urban areas. The integration of the before mentioned approaches of outcome and contextual vulnerability from two different scientific communities (i.e. climate change and disaster and risk research) appears particularly relevant as it allows the analysis of current and existing vulnerabilities as well as future trends. A thorough examination of this kind would need the interaction between at least two different research communities, that is scholars conducting risks and vulnerability research in line with the climate change community’s approaches (e.g. IPCC, 2007) and scholars doing research in line with social science based urban vulnerability research.

3.3.2.3 Urban Adaptation Challenges

The question of how to adapt urban areas to global environmental change is a quite recent issue. There is hardly any agreed upon knowledge available how such a process should be governed and/or steered (Görg, 2010; Kuhlicke & Kruse, 2009). If at all, there seems to be a certain consensus that the adaptation efforts to global environmental change impacts require different types of strategies and responses than traditional adaptation efforts: "*Coping with global environmental change is therefore a long-term and far more costly challenge, which requires different ways of thinking and acting*" (Simon, 2007, p. 77). This section therefore elaborates on some of the challenges associated with the task of adaptation urban areas.

3.3.2.3.1 Governing Uncertainties in Downs-scaling Global Circulation Models

A first adaptation challenge arises from the intersection of downscaling global circulation models to the regional or even to the local level with urban policy making structures. While the technical and scientific challenges involved in assessing the impacts of climate change on urban areas are enormous (Wilby, Beven, & Reynard, 2008), if anything, the institutional challenges involved in using that science for policy making and the development of adaptation options are even greater (Demeritt, 2006; Dessai, Hulme, Lempert, & Pielke Jr., 2009b; Hall, 2007). As well as organisational issues like resource constraints and heterogeneous bureaucratic cultures within government departments and their delivery partners, there are also fundamental normative challenges about how the cultural values underpinning any risk appraisal or risk-based prioritisation should be informed by, and communicated to, stakeholders and the general public. These socio-cultural factors often shape the use of risk appraisal in different risk domains and organisational settings (Beck, 2009; Demeritt, 2006).

In different political contexts, scientific uncertainties about climate change are alternatively amplified to deny the need for any action (McCright & Dunlap, 2003), mobilised as a rationale for immediate precautionary action (Stern, 2006) or framed as something to be resolved through further research (Shackley & Wynne, 1996). In general there are currently two approaches discussed: There is, first, the "predict-then-act approach" which is based on the assumption that further quantification of uncertainties and more accuracy and precision in the assessments of future climate change are necessary to develop effective adaptation strategies. This view mostly reflects the classical understanding of science as a "provider of certainty"; a view which is deeply influenced by a more general, modernist confidence in the power of reason and technology to overcome Nature (Marjolein *et al.*, 2002). Yet, such a view is considered by many scholars as being problematic, since the uncertainties are too profound both on the side of the natural system as well as the societal system and how they mutually influence each other, to simply hope that a more accurate prediction would be possible. The consequences of "predict-then-act" approach may hence be mal-adaptation (Hall, 2007). Therefore, another attempt, the "robust-decision-making" approach is gaining prevalence. It argues that it is more promising to generate policies that are insensitive to the accuracy of predictions about an inherently uncertain future (Dessai *et al.*, 2009b; Dessai & Hulme, 2007; Dessai, Hulme, Lempert, & Pielke Jr., 2009a; Lempert, Nakicenovic, Sarewits, & Schlesinger, 2004; Morgan, 2003). Thus, instead of improving the predictive power of science, it emphasizes the resiliency of policy to climate and other changes in the prevailing boundary conditions of a system.

To give just one example: The question of how to adapt new and existing buildings to climate change is not easy as long as the uncertainties are high with regard to projecting the consequences. Therefore "mechanisms for incorporating uncertain information on future climates" need to be further developed and specified not only in a very general sense but also with regard to the building design (Lisø, Aandahl, Eriksen & Alfsen, 2003; Sanders & Phillipson, 2003). There is need for information and research, both with respect to sensitivities in the build environment and technical solutions to climate changes impacts on buildings (Lisø *et al.*, 2003, p. 208).

3.3.2.3.2 The Uneven Distribution of Adaptive Capacities

A second adaptation challenge is arising from the empirical observation that adaptive capacities are unevenly distributed among different actors, be they governmental, administrative or private; they vary considerably among regions, countries, and socio-economic groups. There is consensus that those groups considered as most vulnerable seldom have an influential voice with regard to how to govern and steer adaptation (e.g. Hardoy & Pandiella, 2009, p. 212).

Particularly on the urban level the challenge is arising that local governments quite often do not have the resources to efficiently address the impacts of climate change. Indeed, local authorities are often overburdened with tasks related to cope with climate change impacts as these are only one part of the bouquet of services they have to deliver. "*Very often, this is mainly true for developing countries, local authorities lack the skills, capacities, and human and financial resources to efficiently tackle with the impacts of climate change on the community*" (Laukkonen *et al.*, 2009, p. 288; cited in; Satterthwaite *et al.*, 2007).

Apart from the lack of missing resources and capacities of local governments, large urban and highly dynamic urban areas are difficult to govern and steer per se. Some scholars therefore argue that such areas are defined by a "*loss of formal governability and control*" (Kraas, 2007, p. 80), on the one side due to the lack of capacities but also the nature of unpredictable and diverse self-regulatory processes. Particularly in megacities effective conventional governance is no longer taking place. They are defined by inadequate or non-existing land-use control, loss of administrative capacities, weak political-administrative decision-making. These processes are going hand in hand with a growth of informal settlement structure with all its implications (Kraas, 2007, p. 81).

3.3.2.3.3 Research Needs with Regard to Urban Adaptation

While the technical and scientific challenges involved in assessing the impacts of climate change on urban areas are enormous the institutional challenges involved in using that science for policy making and the development of urban adaptation options are even greater. Therefore a better understanding of the interplay of science and policy is crucial in this respect. There is a need to address and understand the institutional challenges in using that climate science for policy making and the development of adaptation options on the urban level. While there exist some policy-oriented suggestions, such as resilience-based policies and/or adaptive management strategies, there is a lack of a more empirically based understanding of how uncertainties are framed and contested and how those institutional processes of transferring science to policy inform the development of adaptation strategies. Comparatively little work has been done to think through the practical and institutional implications of the above mentioned uncertainties for decision-making processes on the urban level.

3.3.2.4 Evaluation of the Application Area

Gaps in Scientific Knowledge and Potential to Achieve Scientific Breakthroughs

The topics for future research proposed are of global relevance and need to integrate different disciplinary approaches. Thereby, the topic of 'shrinking cities' has not sufficiently been explored in general but also with regard to risk and adaptation. This topic appears as highly relevant since the risk and vulnerability literature is usually focusing on the negative consequences of rapidly developing urban areas (see above). There is hardly any substantial literature dealing with the negative consequences of a declining or shrinking urban system and how these processes relate to the production of risky and vulnerable conditions (for an exception with regard to infrastructure cf. Moss, 2008). By contrasting rapidly growing and shrinking urban areas and by integrating the climate change community, a true advantage will be generated. Furthermore, to our knowledge there exists no larger international programme addressing the research project as outlined above. Apparently, the research project needs to be interdisciplinary in its setup

Science-policy interplay

Many urban areas are currently struggling with the challenges outlined above. The policy problem is highly tangible and although challenging, it is important that a respective research programme to be developed is accomplishable within a limited time frame. Policy-maker, practitioners as well as authorities and decision-makers and other stakeholders (e.g. NGOs) play a central role as the inherent uncertainties outlined above demand for a trans-disciplinary and policy orientated research design.

Relevance of international policy problem

Policy problems outlined above have been identified relatively recently and it is expected that they gain relevance on the policy agenda as many cities and urban regions are currently developing strategies to reduce their vulnerabilities and to adapt to climate change. It is very likely that the issue will be persistent over the next decades and will becoming even more urgent.

Suitability of the programme to be implemented in the German scientific community

There exists a critical stock of available expertise in the German research community to address the issues (mega-city research, research on shrinkage and research on the consequences of climate change). The programme therefore surely has the potential to strengthen an emerging research and would build its strengths and without duplication of previous programmes but rather by developing a complementary perspective.

3.3.2.5 Research Project Outline

In light of the previous overview about the state-of-the art and the outlined research needs this section gives a more specified idea about how a possible research project should be set up. In a first step the general implications are outlined against the background of the previous argument; in a second step the research design is specified, and, thirdly, the relevance of the overall research approach is evaluated. A potential title for a research project could be as follows: "*Shrinking and growing: Comparing urban dynamics and its consequences for urban vulnerabilities and adaptation strategies*".

The problems with quantifying uncertainties and developing more accurate assessments of future climate change reveal that future research should pay more attention to the question whether to concentrate on the resiliency and robustness of policies, instruments and measures policies that are insensitive to the accuracy of predictions. Research should pay particular attention on how uncertainties are framed and contested and how those institutional processes of transferring science to policy inform the development of adaptation strategies.

The research will integrate expertise from the following disciplines: urban studies, sociology, geography, urban planning and design, hydrology, economics, engineering and climate change modelling. It should to the extent possible adopt a wide geographical distribution of cities (case studies) representative for different urban development patterns with particular attention to rapidly growing cities located in the south and shrinking cities in the north. The research should go well beyond the traditional combination of scientific disciplines exploring the interface between science and the public.

To address the mentioned challenges an inter- and trans-disciplinary research design appears as adequate. While urban studies, for instance, have traditionally been dominated by social scientists and perspectives that have focused on human activity and use of the environment, climate change scholars of focused on better understanding past and projecting future climatic dynamics. The observed complexity and inter-linkages demand for inter- and trans-disciplinary, as well as a intercultural research design. In light of the uncertainties involved in both the projection of future development but also in the decision-making process a multi-stakeholder-oriented and trans-disciplinary research approach seems particular promising. There is a need for generating knowledge based on fundamental analyses and explanations, but also for the creation of applied knowledge for prediction, orientation and decision-making. The regional focus should allow a contrasting research design, which means it should focus on rapidly growing urban areas possibly exposed to severe consequences of climate change (e.g. sea level rise or water shortage) as well as on shrinking cities. In the following a possible research project is specified.

The project should either be a large-scale project or split up in different smaller research projects focusing on well selected case-studies in representative urban areas. In the latter case, the single research projects should be accompanied by an overarching project coordinating and integrating the thematic focus of the other research projects.

3.3.3 Application Area 3: Vulnerability of Complex Systems of Critical Infrastructures, Society and Environment

Against the background of the prognosis of the Intergovernmental Panel on Climate Change (IPCC, 2007) as well as the Stern Report (Stern, 2006), whereby extreme weather events are likely to increase in terms of magnitude and frequency, the set of problems associated with the high dependency of society as a whole and the economy in particular on Critical Infrastructures (CIS) are challenging for both, researchers and decision makers. Recent natural hasard events such as Cyclone Lothar in 1999, Thorsten in 2005 (BNA, 2006) and Kyrill in 2007, as well as the heat wave in summer 2003 (von Hauff & Kluth, 2006), have drastically shown, how vulnerable highly industrialized countries such as Germany are to natural extreme events. In particular their high dependence on CIS played a key role.

CIS are those governmental and private organizations and facilities by which essential services are supplied. These services include food, water, public health services, energy, transport, information and communication, and waste removal and disposal. The failure of CIS can lead to problems of national security, basic supply service and other severe consequences (BMI, 2008). Systems and sub-systems of CIS are at risk worldwide not only because of the growing frequency of extreme events of natural causes, but also because they are increasingly vulnerable to local disturbances. This is, in part, due to the strong reliance of CIS on each other, which may turn a local disturbance into a large-scale failure via cascading events that have catastrophic consequences on society as a whole. For instance, the normal operation of water, telecommunications, transportation, and banking systems is maintained only if there is a steady supply of electric energy. However, the generation and delivery of electric power cannot be ensured without the provision of fuel, water, and various telecommunications and computer services (Bigger *et al.*, 2009). Assessing vulnerabilities and developing solutions for governing the manifold interdependencies of CIS is complex by nature, especially because nowadays CIS are configured in a web of 'system of systems' that has no single owner or operator (IRGC, 2010). Additionally, the gap between increasing dependency on CIS of societies in developed countries and particularly in urban centers and the lack of knowledge on the vulnerabilities of CIS pose a threat (Boin & McConnell, 2007).The major research question is, what are the implications of extreme events and climate change for society in general and civil protection in particular with regard to adaptation challenges and opportunities of CIS (Lauwe & Riegel, 2008; Birkmann & Krings, 2008)?

In the following future challenges regarding ensuring CIS resilience and future research needs are going to be discussed. Thereafter an evaluation of this application area against the already mentioned criteria in section 3.3.1 and 3.3.2 will be conducted to conclude with a project proposal.

3.3.3.1 Scopus Analysis

To assess the current state of development in this field of research, a bibliometric analysis of publications using SCOPUS database has been conducted for the time period of the past 10 years. For the analysis the combination of the key words "critical infrastructure and vulnerability" were chosen. The results show the number of publication in peer reviewed journals in the search space of 'articles', 'proceedings papers', 'reviews', and 'editorial material' that included the 'search terms" in abstract, titles or key-words.

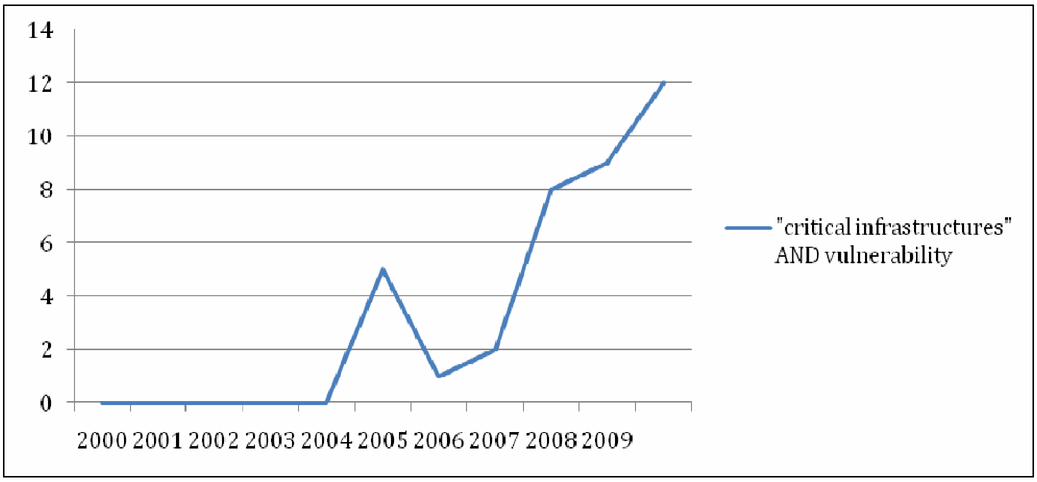

Figure 18: Bibliometric Analysis using the key words "Critical Infrastructures" and "vulnerability".

Figure 18 shows that the number of publications using these key words has increased from 2 publications per year in 2004 to 12 per year in 2009, which is a significant increase and shows that the relevance of CIS in vulnerability research gradually increases but is still very high in terms of publication output. The implications of these trends will be outlines in the following sections.

3.3.3.2 Coupled Systems of Critical Infrastructures, Society and Environment in the Context of Water related Fast Onset and Creeping Hazards

CIS are due to their importance for the functioning of societal processes and their vulnerabilities with respect to climate change and extreme natural hazard impact well recognised in the Strategy for Adaptation to Climate Change (BMU, 2008). CIS are impacted by fast onset and extreme events in various ways. As with other types of man-made hazards such as terror attacks or accidents, CIS components can be directly damaged and affected by extreme water related weather events. A prominent example from Germany is the electricity blackout in the „Münsterland" caused by a snow storm in winter 2007, which led to emergency situations for the population due to temperatures below zero (Birkmann & Krings, 2008). On the other side, the functionality of CIS can be disturbed also by long-term and slow onset environmental change; e.g. the heat wave in 2003 reduced the water availability for power plant cooling systems, which resulted in lower levels of electricity availability (Birkmann & Krings, 2008).

At the same time environmental change and extreme water related hazards as a consequence of climate change will alter the demand for CIS services. Their increase or decline is embedded into overall processes of societal transformation (technological innovation, resource utilisation and distribution, consumption patterns, and habits of way of life) and is socially very differentiated. Although, social groups such as elderly, chronically ill, and other disadvantaged groups are the same way exposed to extreme events, such as heat waves or floods, they might suffer more harm than others requiring changes in the utility and dependency on CIS services (see EU commission DG-Health, 2007; BMU, 2008, p. 18; Koppe *et al.*, 2004).

To conclude, when studying coupling effects at the interface between CIS, society and environment it is necessary to investigate on the one side how climate change and water related stress affect the performance and availability of CIS services and on the other side how demand and dependency patterns change in the course of sudden extreme events and long-term changes in the environmental system hereto referred as creeping events. The heat wave in 2003 has demonstrated the conflict between an increase in the demand for electricity and the decline of the electricity availability (see BMU, 2008).

The impact and relationship of direct and suddenly occurring extreme events as well as long-term creeping change of ecosystem services on coupled CIS and their effects for human systems is schematically shown in Figure 19.

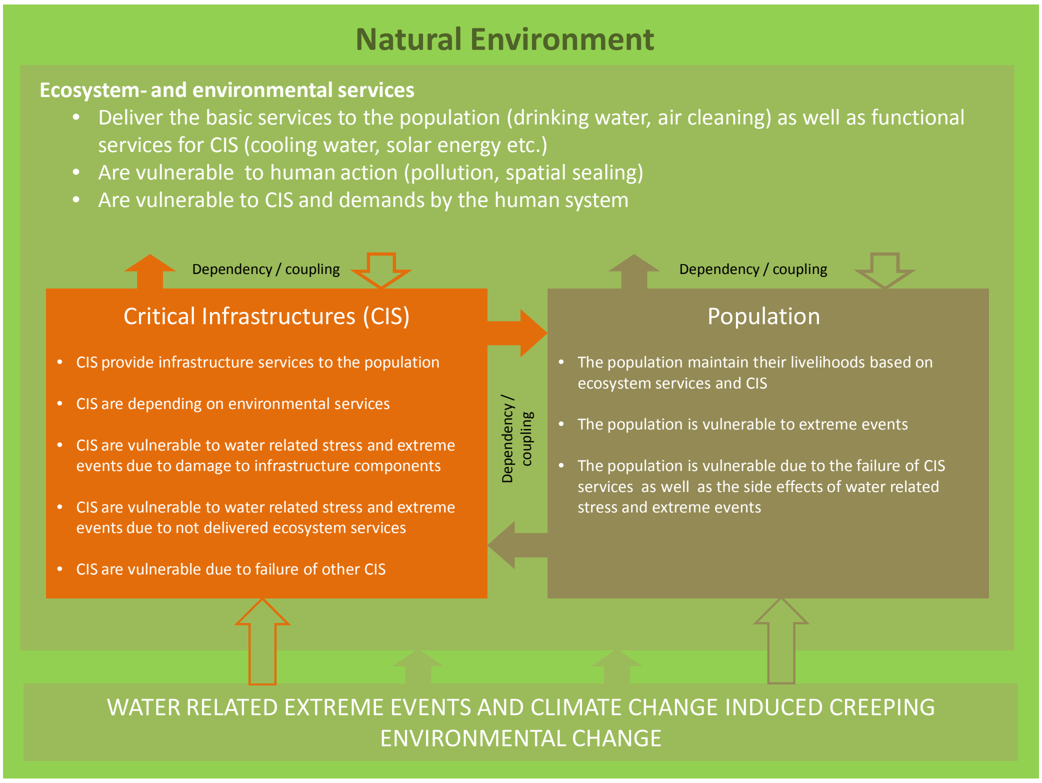

Figure 19: Impact relationship between population, CIS and water related extreme events related to global climate change (Source: adapted from Birkmann & Krings, 2008).

3.3.3.3 Research Needs and Gaps

Future research needs to address in an integrated manner the coupled social, environmental and technical system, in which CIS are embedded by focusing on the interplay between vulnerability patterns and the response activities of the population related to water related sudden and slow onset events. Based on the literature on CIS analysed, most of research on CIS has been carried out in the United States of America focusing on CIS vulnerabilities related to man-made hazards, such as terror attacks, accidents and CIS systems inherent fragilities. Major research topics on failure propagation, transnational CIS vulnerability, quantifying infrastructure interdependencies and conducting CIS reliability modelling and analysis could be identified (see Auerwald *et al*., 2005; Van Der Vleuten *et al.*, 2010; Panzieri & Setola, 2008; Sultana & Chen, 2009; Apostolakis & Lemon, 2005; Ezell, 2007; Gheorghe & Vamanu, 2004). Although there has been considerable research on CIS conducted it is restricted only to man-made hazards which have different impact patterns then fast onset and creeping water related hazards of natural origin due to different functions of spatial coverage, intensity and propagation. In addition, the coupling perspective between CIS and social and environmental systems is missing in current CIS research. It focuses solely on CIS systems' inner configurations, thus in an isolated manner from environmental and social processes and interdependencies.

With regard to vulnerability of CIS to water related extreme events, recent research has been conducted at UNU-EHS on how to assess the vulnerability of electricity and water supply infrastructures in terms of their likelihood to fail during the course of a flood event. The research aimed at developing a guideline and method of analysing and evaluating the vulnerability of the different single CIS components regarding their exposure, functionality (relevance), technical redundancy and organisational preparedness. In a relative ranking the results were brought together to quantify the level of vulnerability for each of the identified components (BBK, 2009). Although the research focuses on environmental stressors it does not account for impact chains and cascading effects of critical infrastructure failures on other supply networks and the population as well as the economy in highly technical, industrialised and service dependent societies.

Future research needs to focus more on the identification of the links between vulnerability patterns of social-ecological systems and CIS. Since CIS are key for productive systems (.g. agricultural and industrial systems) and because they utilise and distribute environmental and processed resources, their function depends not solely on technical capacities but also on quality standards of environmental conditions and services. The significant reduction of the capacity of power plants during the heat wave 2003 on the river Neckar was not solely caused by technical limits; rather the water temperature of the Necker reached a critical value that restricted the further warming of these rivers by power plants and their "cooling processes". Consequently, the vulnerability of CIS and their services in the context of water related hazards is linked with complex coupling processes of social-ecological and socio-techno-ecological systems. These interdependencies and interactions often have been overlooked in recent risk assessments. In many assessment approaches solely the physical exposure of CIS is taken into consideration.

Thus, new challenges also arise for governing CIS under conditions of increasing water related disaster risks and climate change impacts. And how does the security of CIS services can be guaranteed under conditions of transformations of CIS governance systems, such as trends of deregulation and privatisation of CIS service provision (see De Bruijne & Van Eeten, 2007). Also in the context of these transformations, how to develop protection goals and standards for threats that are largely unknown?

Thus, the following future research topics are proposed that need be dealt with in an integrated manner. In accordance to the Strategy for Adaptation to Climate Change, CIS shall be addressed in the following sectors: public health, emergency services, water, energy, finance, transport and logistics. Considering these sectors and their different characteristics, research has to be carried with the following objectives:

- Development of a conceptual framework to capture the vulnerability of complex, coupled systems and interdependencies between CIS, society and environment and potential cascading effects.
- Conduction of a comparative analysis of types of man-made and water related fast and slow onset hazards and their effects on different CIS.
- Evaluation of the influences of increasing deregulation and privatisation of CIS services on their overall vulnerability and adaptive capacity and related effects to society and development of recommendation for risk and adaptive governance of CIS.
- Development of vulnerability assessment criteria and protection standards for resilient CIS.
- Evaluation of opportunities, challenges and limitations of the adaptability of CIS and the role of organisational and technical instruments for adaptation.
- Evaluation of future and innovative CIS such as “smart grids” (electricity) regarding their vulnerability and resilience in the context of CIS-interdependencies and coupling effects of CIS failures.

3.3.3.4 Evaluation of the Application Area

Potential to Achieve Scientific Breakthroughs

The research challenges outlined in the previous section have high potential to achieve scientific breakthrough because on the one hand only little research has been conducted on water related risk research of CIS linked to social-ecological coupled systems allowing for fast progress in generating new knowledge. On the other hand, substantial CIS research related to man-made hazards has been conducted that can provide significant input for advancing in water CIS research related to water related risks and vulnerabilities.

Science-Policy Interplay

CIS research deals with questions of service delivery capacities of mostly governmental but also private facilities whose tasks are to sustain human security and well-being of the economy, the environment and at large citizens. In this respect the protection of CIS against emerging threats such as water related fast and slow onset hazards are sovereign duties, which is critical for governments’ performance of welfare provisions. Thus, conducting research and developing solutions how to govern CIS requires from the beginning the involvement of governmental and no-governmental organisations working in specific CIS sectors and closely together with CIS operators, authorities involved in civil and environmental protection and policy and finally groups of end-users who depend on CIS services: Taking the example of the risk governance framework of Renn (2008) and the IRGC (2005) stakeholder involvement is required for all governance phases; starting with problem framing and continuing with vulnerability assessment and the evaluation and development of management options.

Relevance of International Policy Problem

Systems and sub-systems of CIS are at risk worldwide not only because of the growing risks worldwide associated with water related extreme events, but also because CIS are increasingly vulnerable to local disturbances. This is, in part, due to the strong reliance of CIS on each other, and a result of globalisation which led to worldwide economic integration and increasing interconnectivity of CIS. Consequently, local disturbance are turned into a large-scale failure via cascading events that have catastrophic consequences on society as a whole.

Suitability of the Programme to be implemented in the German and European Scientific Community

Germany bears a great potential to form a multi-disciplinary group of scientists representing the complex nature of the application area. Apart from research domains related to the social-ecological dimension of CIS, research capacity of groups in Germany particularly focusing on CIS is limited. Up-to-date research on CIS has been or is being carried out by PIK, UNU-EHS, DLR, CEDIM and the IRGC. Respective research programmes are still in its infancy regarding capturing the entire dimension of vulnerability of complex systems of CIS, society and the environment.

3.3.3.5 Research Project Outline

A research project shall focus on the development of a by CIS operators and CIS policy makers well accepted and theory based conceptual framework for assessing the vulnerability of complex and coupled systems of CIS, society and the environment.

For this and for the development of a classification scheme of the different vulnerabilities of complex coupled systems of CIS, society and the environment and to conclude with the development of protection goals, standards and best practice governance guidelines for coupled CIS systems, the following three different research components shall be addressed and finally brought together:

1. Conceptual and empirical applied research shall take into account a multi-hazard perspective since the challenges for governing the vulnerability of complex and coupled systems of CIS, society and the environment are whether and how different hazard types and vulnerability patterns can be accommodated in a multi-hazard resilient CIS approach and how to deal with trade-offs. Thus, the project shall focus on two different threat characteristics: water related fast onset hazards, such as floods and flash floods and slow, creeping onset hazards such as heat waves and sea level rise.
2. Apart from addressing different threat scenarios (slow and fast onset), the project shall also compare different CIS systems. For their differentiation and selecting a representative sample, research shall be carried out according to the following criteria: Degree of relevance of CIS as service provider for other CIS services (e.g. electric power supply), their function (e.g. provision of health, food) and dependency on natural resources to explore the coupling effects at the interface between CIS, society and the environment.

3. The above mentioned two research components shall be embedded in an analysis of general framework conditions in which CIS operate and that influence the vulnerability of CIS to water related fast and slow onset hazards. Among others the three most relevant framework conditions that need to be explored are: Trends of privatisation and decentralised operation of CIS changing the regulatory culture of CIS governance, the increasing challenges to govern the complexity of CIS global interdependencies, and the innovative development of CIS in terms of new CIS systems such as "Smart Grids" and the ongoing digitalisation of CIS operations.

In order to be scientifically sound, a case study based research design should be developed that allows for a systematic global comparison of the vulnerability of complex coupled systems of CIS, society and the environment. But depending on project proposal requirements case studies can also focus on specific geographical areas of interest. Nevertheless, the requirement to design research activities that take into account CIS relevant political, economic and environmental system boundaries shall not be neglected.

Since water related CIS governance is considered as an important dimension of social-ecological research a trans-disciplinary and multi-disciplinary research consortia composed of researchers and decision makers representing expertise in law and policy, economic, political, social, engineering and natural sciences shall be set up.

4 Theme Cluster 3: Governance of Transformation

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4.1 Introduction and General Overview

4.1.1 Significance of the Theme

There was overall agreement during the expert workshop in February that major transformations towards sustainability are the key challenge in water resources management in general and for water resource governance in particular. Major structural changes are needed in all domains of the water sector but it is by no means evident how they should be governed if they can be governed at all.

The methods and tools used by industrialised societies to manage water supply, wastewater, and stormwater were established in broad outline over a hundred years ago. These methods were highly successful in addressing development and sanitation objectives, but today their functional and economic effectiveness in fulfilling environmental, quality of life, and other objectives is often questioned. Conventional methods such as physical, biological and chemical treatment are evolving in new directions. At the same time, new technologies, and old ones in newly refined forms, are emerging, presenting new options for water systems design and management (e.g. small footprint and decentralised systems). Novel institutional and managerial approaches are similarly emerging at a rapid rate. Indeed, a whole range of insights and changes in perspective have started to undermine the basic assumptions on which traditional water management has been based. For example, (i) water crises are now recognised as often being crises of governance and not of resources or technological problems (ii) increasing uncertainties due to climate and global change reduce the predictability of the boundary conditions under which water management has to perform (Milly *et. al.*, 2008), (iii) the polluter-pays-principle and source control options are more commensurate with sustainable water management ambitions and have gained increasing support over technical end-of-pipe solutions (Larsen & Gujer, 1997), and (iv) Integrated Water Resources Management has been vigorously promoted as a more efficient and effective response to multi-criteria resource management problems (GWP-TEC, 2000).

Uncertainty about climate trends amplifies existing challenges in our efforts to bring about sustainable management of water resources. Critical voices have stressed the need for a radical paradigm shift to avoid the failures we already experience in prevailing environmental resources management approaches. These failures can be attributed to mechanistic and technocratic strategies that neglect complexity and the human dimension (Holling and Meffe, 1996; Gleick, 2003; Pahl-Wostl, 1995, 2007a). Climate change and the concomitant increase of extreme weather events have exposed the extent to which water resource management regimes are vulnerable (Pahl-Wostl, 2007b; Opperman *et al.*, 2009).

However, despite increased awareness for the need for change, change is slow. Water resource governance and management systems have often evolved over long periods of time and are closely intertwined with technological infrastructure and other artefacts (e.g.

Geels, 2002; Pahl-Wostl, 2007a, 2007b). Co-evolutionary development and path dependence have generated an interdependence of system components which is important to guaranteeing the functioning, and the convergence of the expectations of actors. The downside of such interdependence is that it prevents change, and that it generates what one may refer to as lock-in-situations, a term introduced in economics to refer to the dominance of established technologies despite inferior performance due to path-dependence. Governance of transformation is the most significant challenge underlying water management.

Governance of transformation was identified as key theme in the expert in Osnabrück workshop in February 2010. Four topics were identified where governance of transformation is of paramount importance to improve sustainability:

1. Developing and Evaluating Infrastructure Transformation (section 4.2.1)
2. From Waste Water Treatment to urban Metabolism (section 4.2.2)
3. From Flood Protection to Resilient Regions (section 4.2.3)
4. Accepting the Limits: Building Resilience in Water Scarce Regions (section 4.2.4)

Before analysing these topics and the corresponding relevance of governance of transformation in more depth the next section will summarise recent developments and major research trends in water governance in general.

4.1.2 General Reflections on Water Governance

Governance embraces the full complexity of regulatory processes and their interaction. The evolution in the discourse from “government” to “governance” implies a change in thinking about policy processes. The notion of government as the single decision making authority, where state authorities exert sovereign control over the people and groups making up civil society, has been widened by the notion of multi-level, polycentric governance where many actors in different institutional settings contribute to policy development and implementation. ‘Governance’ takes into account the increasing importance of modes of governing, where non-state and private corporate actors and networks participate in the formulation and implementation of public policy or develop policy instruments that co-exist with existing government policy processes (Rhodes, 1997). Governance encompasses coordination and steering processes to influence behaviour by formal and informal institutions (Scharpf, 1997).

The human dimension, long neglected by water scholars and practitioners, increasingly appears to be the most fertile frontier for innovations in research, policy and practice. To assess the current state of development in this direction we made a bibliometric analysis of publications using the SCOPUS data base. Different combinations of key words were used to define “search terms”. The search results include the number of publications in peer reviewed journals in the search space “articles and reviews” that included the “search term” in the abstract, title or key words.

Search Term - (search state 21.03.2010)	2000	2003	2005	2006	2007	2008	2009
Water AND Governance	18	39	58	86	106	144	164
“Water Management” AND Governance	4	24	26	28	43	64	71
“Water Management” AND Adaptive	8	20	23	17	29	36	53
“Water Management” AND Integrated	88	126	188	193	266	289	282
“Water Management” AND Technology	151	172	234	263	321	339	319
Water AND Technology	1720	2308	3086	3405	4055	4135	3994

Table 1: SCOPUS analyses of trends in publications in peer reviewed journals

Table 1 highlights the continued dominance of technical over social perspectives. Publications in water-related science show still a decisive advantage for technology over governance, and “water management AND technology” over “water management AND governance”. This despite overwhelming recognition that many water related problems have their origin in governance failure. However, one must also acknowledge the increase of publications with a social science focus over the past decade.

Despite these promising developments, finding general patterns in water governance regimes and the dynamics of change without resorting to simplistic blueprints poses still considerable challenges. Defaulting to generic and simplistic approaches will not address the complexity of real governance regimes. Panaceas have proven to be weak in their explanatory power and not very useful or even detrimental for policy advice (Ostrom *et al.*, 2007; Ingram, 2008). Unfortunately, technological or institutional panaceas such as the privatisation boom were often automatically applied to water issues without long-term monitoring and revision that would have responded to failure earlier. What is required may be called a diagnostic approach supporting context-sensitive analysis without producing insights being limited to a specific case and thus not transferable.

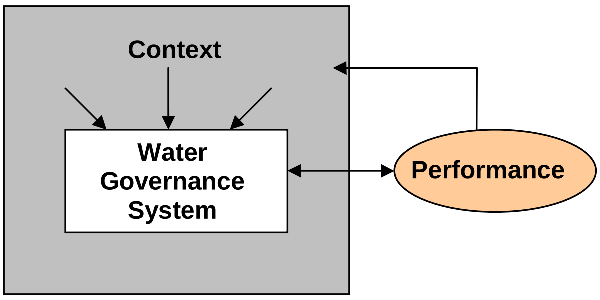

Figure 20: Framework making a distinction between performance - water governance regimes – context.

Figure 20 depicts a simplified framework of analysis supporting a diagnostic approach. Such analyses aim at relating the performance of a water governance system to its dynamic and structural characteristics taking into account the influence of the environmental and societal context.

Regarding performance it is of specific interest to analyse which characteristics of a governance system lead to high adaptive and transformative capacity without jeopardising good governance principles. Hardly any such kind of large scale comparative analyses of governance regimes exist. This may partly be attributed to the lack of shared frameworks for analyses which render studies that have been conducted independently largely incomparable.

Some frameworks have been suggested recently. A diagnostic approach towards governance has been promoted in the context of designing institutions for sustainable governance of human-environment interactions Young (2008) put forward a set of principles for the "diagnosis" of institutional problems based on experience from research in the IDGEC programme. Ostrom (2007) suggested organising variables of interest in the study of social-ecological system in a nested, multi-tier framework. A management and transition framework was developed by Pahl-Wostl *et al.* (2007a and in press) to analyse multi-level water governance and management regimes. All approaches have flexibility and enables the analyst to choose and tailor his/her inquiries according to the needs of the issues under consideration.

It is also evident that such an approach relies on a systemic perspective to embrace complexity and the wealth of interactions characterising governance regimes. This requires an interdisciplinary approach in the social sciences and across the social-natural science interface. Both requirements pose considerable challenges to scientific communities. Interdisciplinary collaboration in the social sciences is fraught with difficulties. Conceptual and methodological foundations are often (perceived to be) incompatible. Shared databases and protocols scarcely exist. Any new programme should aim at overcoming this problem and support collaboration in professional networks that adopt shared practices to build a knowledge base as a foundation for dealing with the major global change challenges of the present and the future.

4.2 Application Areas

4.2.1 Application Area 1: Developing and Evaluating Infrastructure Transformation

In many cities major infrastructure development is required. This may apply to cities with an existing urban infrastructure which proves to be non-sustainable in the long-term. This may apply to fast growing cities in developing and transition countries where infrastructure development cannot keep pace with the fast growing settlement. What is lacking are systemic policy, planning and implementation processes that take into account the cultural, socio-economic and political conditions and develop context specific societal (e.g. legal regulations, technical skills, supply and maintenance networks) and technical – socio-technical – infrastructure. Such processes should also take into account unintended side effects and build infrastructure systems that are flexible and robust to changes in the boundary conditions such as population, climatic conditions etc. Furthermore financing and risk management pose considerable challenges. Finally methods need to be developed to analyse success and failure of governance processes and the transferability of insights.

4.2.1.1 Gaps in Scientific Knowledge and Potential to Achieve Scientific Breakthroughs

To identify the amount of scientific work invested in the topic of developing and evaluating infrastructure transformation in the water sector for water supply and sanitation we used a converging approach. We separated the research into development from research on evaluation (level 1 key word). For both fields of research we started with these more general issues and then focussed on transformation (level 2 key word) and further converged onto infrastructure (level 3 key word) and then specified infrastructure into water supply and sanitation (level 4 key word). Finally we separated urban from rural (level 5 key words).

While infrastructure and sanitation are clearly defined concepts that will not cause much confusion in literature searches, the concept of transformation is ill defined and has different meanings and definitions in different bodies of literature. Timmermans (Timmermans, De Haan, & Squazzoni, 2008) gives an overview of the scientific use of the concepts of transformation in scientific fields ranching from the natural sciences to the social sciences. Table 2 gives a summary of these concepts. From this table we use transformation, transition, innovation and structural change as our key words.

Scientific field	Concept used for structural change
Natural sciences	Transition
Organisational sciences	Transition
Policy sciences	Policy punctuations, policy innovations, radical change
Economics	Structural change, system innovations, transformation, transition (heterodox), transition (state economic systems)
Sociology	Transition, transformation

Table 2: Concepts expressing structural change in different scientific fields.

key words search													
level 1	results		level 2	results		level 3	results		level 4	results		level 4	results
governance	18390												
policy	162787		transformation	10012									
implementation	88866		transition	11451					water supply	12		Urban	1
management	317643	AND	structural change	4179	AND	infrastructure	337	AND	sanitation	2	AND	Rural	0
adaptive	63846		innovation	15881									
flexible	39739												
resilience	6373												
			transformation	2733									
evaluation	195365	AND	transition	2393	AND	infrastructure	119	AND	water supply	0	AND	Urban	0
			structural change	1008					sanitation	0		Rural	0
			innovation	1822									

Table 3: Search results according to specific key words.

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The results of this search are presented in the Appendix[2] (which can be found on CD).

From this analysis some relevant conclusions on the gaps in scientific knowledge related to developing and evaluating infrastructure transformation can be arrived at:

Development

- A large body of literature related to the governance of transformations exists. These literatures are mainly from the social and environmental sciences and from engineering. Publications from engineering cover a wide range of issues of which some are relevant to the current topic while others are less relevant.
- The amount of the governance of transformation literature related to infrastructure is limited to a few hundreds of publications. These publications are mainly in the field of social and environmental sciences and from engineering. Again publications from engineering are not always relevant.
- A focus on the governance of transformation of water supply and sanitation infrastructure is virtually absent in the scientific literature.
- A further focus on urban development, where problems related to water supply and sanitation are prominent, is only addressed in a single pioneering publication.

Evaluation

- A large body of literature addresses innovation. The focus on infrastructure is limited and a focus on water supply and sanitation is absent.

A gap of scientific knowledge exists in the translation of governance of transformation to infrastructures and more specific water supply and sanitation in urban areas. A research programme surmounting this gap in scientific knowledge is thus necessarily interdisciplinary and needs to build a bridge from the social to the natural and engineering sciences or vice versa. Expected outcomes have the potential to open up an internationally visible and innovative research field. The availability of a limited number of pioneering publications in this field shows that such an endeavour is feasible. Especially when organised as a research programme it seems feasible to surmount the progress made by individual pioneering researchers.

4.2.1.2 Science-Policy Interplay

In Europe, urban water supply and sanitation was mainly developed under the responsibility of municipalities. This institutional context is highly correlated with the mainstream technology, piped water and sewerage systems, and framing of the problem in terms of hygiene and health (Geels 2006). Increasingly municipal responsibilities are transferred to autonomous and quasi-autonomous non-governmental organisation like water supply companies while sewerage (sanitation) remained largely a municipal task. Often these organisations have their own professional and industrial associations. Currently some of these companies develop into multinationals managing and developing water supply and sewerage systems worldwide (e.g. Suez-environmental).

2 Verweis auf die CD.

Stakeholder categories	Examples
Citizens	As consumers or partners in community initiatives
Local and regional administrations	Municipalities, water authorities, state governments (Lander)
Local and regional Water supply and wastewater companies	(quasi-)autonomous non-governmental organisation like Gelsenwasser AG, Berliner Wasserbetriebe and their international counterparts
Multinational water and waste industry	Suez-environment and Eurawasser
National governments	federal government, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)
European Union	Urban Waste Water Treatment Directive (91/271/EEC) of 21 May 1991, The Drinking Water Directive (98/83/EC) of 3 November 1998, ACP-EU Water facility
United Nations	WHO, UNESCO, Water Decades
Professional and industrial associations	Association of Electricity and Water Utilities BDEW, VKU (association of municipal utilities), DWA (professional association for water and sanitation) etc.
Universities and knowledge institutes	civil engineering, sanitary engineering, social and policy science departments of universities,
Consultants	Fichtner Group, DIWI etc.

Table 4: Examples of stakeholders for each stakeholder category.

An interaction with this development a consultancy and supply sector emerged that covered water purification, waste water treatment, piping and sewerage systems etc. Furthermore sanitary engineering became part of the curricula and research agenda's of mainly technical universities and knowledge institutes. In relation to water supply and sanitation activities in developing countries, public and users participation became an issue and shifted water supply and sanitation issues onto the agenda of the social sciences. While governmental involvements in the development and management of water supply and sanitation declined, governmental involvement in setting drinking water standards and standards for sewerage collection and treatment increased and are currently addressed at the European and Global level. Especially, UN institutions are active in this field (e.g. WHO standards for quality & quantity of drinking water). UN initiatives like the International Decade for Action – Water for Life manage to keep water supply and sanitation issues high on the global agenda. This creates a supportive climate for meaningful science – policy connections. Multinational water corporations constitute both are interesting object of research and partners for implementation.

Table 4 shows a rich variety of relevant stakeholders, objects of research and partners in a research programme. Cooperation with these partners can improve the efficiency and effectiveness of a potential of a research programme on developing and evaluating infrastructure transformation to have a real impact. Careful selection of partners and a clear focus on transformation is however a necessity; many organisations in Table 4 have established positions and interest in the sector and transformation is not their core business. Especially, EU, UN and national programmes on water supply and sanitation offer ample opportunities to connect a research programme to developing policy processes.

4.2.1.3 Recommendations for Developing the Research Area

From our analysis it appears that a gap of scientific knowledge exists in the translation of governance of transformation to infrastructures and more specific water supply and sanitation in urban areas. A research programme surmounting this gab in scientific knowledge is thus necessarily interdisciplinary and needs to build a bridge from the social to the natural and engineering sciences. Expected outcomes have the potential to open up an internationally visible and innovative research field. The availability of a limited number of pioneering publication in this field shows that such an endeavour is feasible. Especially when organised as a research programme it seems feasible to surmount the progress made by individual pioneering researchers.

The transformation of water supply and sanitation infrastructure can be and are both studied as **socio-technical systems** (STS) and as **socio-ecological systems** (SES). They are socio-technical systems because of the embeddedness in and interaction of their technology in a wider social environment. They are SES because water supply and sanitation systems are endogenous to the ecosystems from which they abstract resources (Toonen, 2010; Ostrom, 2009). This combination of SES and STS characteristics distinguishes urban water supply and sanitation from other infrastructure, which are largely studied ad STS.

The most prominent theoretical concept used to analyse and describe socio-technical transitions is the multi-level perspective (Geels, 2002; Rip & Kemp, 1998; Kemp, 1994; Schot, Hoogma, & Elzen, 1994). The multi-level perspective distinguishes three heuristic analytical concepts: niche innovations, socio-technical regimes and socio-technical landscape. The socio-technical regime refers to cognitive routines shared by an engineering community, scientists, users, policy makers and special interest groups. In technological niches, radical novelties emerge while niches act as ‘incubation rooms’ protecting novelties from the scrutiny of existing markets (Kemp, Schot, & Hoogma, 1998; Schot, 1998). The socio-technical landscape forms an exogenous environment of macro-economic development, deep cultural patterns and macro political developments beyond the direct influence of niche and regime actors. Using these three concepts, transitions come about through interaction between processes at these three levels.

The combination of the STS and SES concept is not only relevant to cover the characteristics of the systems under study, urban water supply and sanitation infrastructure, but also because their combination covers transformation or transition, a long term perspective and governance in relation to sustainable development

With transition management as a notable exception, research on the role of individuals in transformations or transitions has mainly focussed on description and historical analysis. Transition management assumes that a structure for collective entrepreneurship, namely the so-called transition arena, can be established to facilitate or manage radical change (Loorbach, 2007). Within the field of policy entrepreneurship ample scope exist to develop prescriptive theories addressing the governance of transformation based on the role of individuals. Relevant theoretical frameworks can be found in the literature on transformative leadership (Bass, 1997), business entrepreneurship (Moon, 1999), psychology (Conger & Kanungo, 1987) and change management (Fiol, Harris, & House, 1999; Lewin, 1951).

4.2.2 Application Area 2: From Waste Water Treatment to Urban Metabolism

The rise of **urban areas** is one of the main challenges that societies are facing today. In 2007, for the first time in history more humans were living in cities than in the countryside. For many authors the 21st century will become the “urban age”, i.e. urbanisation will be regarded as the phenomenon of the new century. It is expected that the world’s urban population will increase by 3 to 6 billion over the next 50 years (Drangert and Cronin, 2008). This trend does not only include increasing numbers of inhabitants, the increasing economic power of cities and urban agglomerations and increasing urbanisation rates, but also changes in resource flows within cities and between cities and their hinterland. It has to be stressed that it is not only the rise of megacities that marks this development. However, the developments in megacities can be seen as the tip of the iceberg, where transformation processes take place more rapidly and with a particular impact on human life and the environment.

Water management has always played a central role in urban development. At the beginning of urbanisation, cities were founded in places with favourable natural conditions. Next to the provision of agricultural products, the availability of and access to water was one of the decisive factors for selecting certain sites for founding cities. Many cities are located in the vicinity of water resources, along rivers or in coastal areas, with direct access to water with its diverse uses (water as a resource, e.g. as drinking water or for use in production; access to waterways; water as a medium to absorb city waste and wastewater).

While in the beginning of urban development the use of water in its diverse functions was unregulated, over time certain decisions were made about the allocation and the use of water. Cities decided upon the way in which water resources could and should be used (joint investments in water-related infrastructure, the access to water for its users, the regulation of water markets, the responsibilities, financing, building and organisation of wastewater infrastructure and so on. Thus, the decisions over water uses and water allocation were becoming an issue of **water governance**. This means that these decisions were not based solely on individual choices, but on joint (common; private and public) decisions with respect to water resource use, access to water and water allocation etc. In other words: (implicit or explicit) ‘property rights’, i.e. rights to use, manage or benefit from water, formed the basis for using and allocating the resource.

The most visible trend of water-related changes in cities in the past was the provision of **centralised infrastructure** in the cities of the developed world (Europe and the United States, but also in many other parts of the world such as Asia or Latin America). Huge water-provisioning services (pipelines; pumping stations) were built, enabling the far-reaching transportation of freshwater to city households and businesses. At the same time wastewater was centrally collected by canals and sewage systems with central treatment plants that served as end-of-pipe technologies. Today, in many European urban countries and in the US more than 90 percent of urban wastewater is collected by central sewage systems and treated in wastewater treatment plants.

There have been numerous indications that these **centralised systems are neither suitable nor sustainable for future developments**, in particular with regard to countries outside of Europe and the U.S.:

- The increase in the population in many parts of the world is above an annual rate of 2 percent, with high differences between cities. A high share of this population growth is informal, i.e. migrants entering the cities from rural areas are not officially counted, and often settle in areas without sanitation and sewerage systems – these are very often the favelas at the urban fringe. It is very unlikely that the centralised urban infrastructure systems will grow at a similar rate in the future to cover the needs of the population.
- In other urban agglomerations the population is shrinking, e.g. in East Germany or in the former socialist countries of Central and Eastern Europe, but also in some other old industrial cities in Europe or the U.S. (e.g. Liverpool, Detroit etc.). This leads to problems in maintaining and financing the existing centralised water-related infrastructure. It is becoming more and more difficult to distribute the increasing share of fixed costs among existing water users.
- It is not only population growth but also climate change that is increasingly leading to water scarcity in many urban areas of the world. Hence, global change trends such as population developments, technological change, international trade, global climate change etc. overlap.

These urban transformation trends are leading to **new challenges in water management**:

Firstly, the existing infrastructure systems of the industrialised countries that are dominated by the paradigm of "centralised supply" are reaching their limits. They are at risk due to population change, technological change, climate change and ongoing transformation patterns. Instead, **new (decentralised) forms of provisioning water and wastewater treatment** will be required. This aspect, which is still oriented towards the water sector as such, amplifies the need for water re-use systems and other new technological systems for example in order to satisfy the needs of people living in urban areas.

Secondly and closely related to this, there are signs that the **perspective on wastewater treatment aspects is too narrow**. Instead, water resource systems have to be considered in a broader frame. In the case of wastewater treatment it is only the wastewater stream that is considered and optimised. Solutions have always been (and still are) only developed against the background of cleaning-up wastewater in order to protect inhabitants against diseases and improve hygiene. While this perspective on health and sanitation was justified in the 19th and 20th century, nowadays many of these sanitation aspects have been resolved (notwithstanding that new pathogens and pollutants are still causing major problems for the treatment of water) and the sustainable management of the resource 'water' becomes the focus. This broadens the perspective in several dimensions:

- from considering waste and wastewater streams to considering entire water flows – i.e. the various dimensions of water, including surface and groundwater resources, quality and quantity issues have to be included;
- from considering only specific sectors of the society and the economy (namely those that pollute and cause unhealthy water conditions) to *all* sectors that use and allocate water, including the entire demand side (private households, industry, agriculture, businesses) – thus water is a system and component which interacts with other systems;

- from considering blue water (i.e. water flows within the city and between the city and rural areas) to considering green water (i.e. the water use embedded in agricultural products);
- from considering technical aspects of water management to considering socio-economic aspects (e.g. the acceptance of water allocation and distribution rules; the definition of property rights; aspects of fairness and distribution) – technical systems alter the attitudes and behavioural patterns towards a resource; in addition, there is an interrelationship between water, and social and economic development.

These aspects that reach far beyond water treatment and that cover urban water flows in all its dimensions can be referred to as the **urban metabolism**. In the following we take a closer look at the urban metabolism and stress the impact of this concept on the need for and design of water-related governance structures.

4.2.2.1 Gaps in Scientific Knowledge and Potential to Achieve Scientific Breakthroughs

Urban metabolism analysis is a means of analysing and quantifying the overall fluxes of energy, water, material and wastes into and out of an urban region. Analysis of the urban metabolism can provide important information about energy efficiency, material cycling, waste management and infrastructures in urban systems (Sahely, Dubbing, & Kennedy, 2003). Urban metabolism quantitatively measures a city's impact on the natural environment (Warren-Rhodes & Koenig, 2001).

Metabolism as a **concept** emerged from ecological research and was only transferred to urban systems in recent decades. The origins stem from industrial ecology, history, environmental history and the history of technological change. The strong focus on history can be seen against the background that primarily change processes over a certain time period are analysed. While some of the studies cover centuries, e.g. from the beginning of industrialisation to the present (Barles, 2007), other studies focus on a much smaller time horizon – decades of about 10 to 20 years (Zhang *et al.*, 2008; Sahely *et al.*, 2003; Warren-Rhodes & Koenig, 2001).

With respect to existing literature on urban metabolism, **four types of studies** focussing on **urban metabolism** can be distinguished:

1. **Regional case studies** focus on a specific region, be it a city or a certain area. Available studies dealt with Puerto Rico, Shanghai, Berlin, Paris, the southern Appalachians, cities in the United States, Toronto, Hong Kong, and Tianjin (see case studies in the Appendix[3]). While some studies take a more traditional perspective, analysing the impacts of water pollutants on the environment (Puerto Rico, Berlin, the Appalachians study), others are broader, taking the entire flows (resources, materials, emissions, water) into consideration (Paris, United States). While these studies prove to be valuable for understanding urban metabolism in every single case, they also exhibit that there is a lack of coherence and joint concepts.
2. **Ecological studies** mainly deal with the ecological impacts of urbanisation. The focus is on ecological functions and services, e.g. the provision of clean water, protection from water-borne diseases, flood control, and the support of recreational ecosystem

Kommentar: Footnote schreiben.

3 Verweis auf die CD.

services. The studies have a narrow focus by analysing selected impacts of urban areas on biodiversity. How do urban forests influence urban metabolism? What is the influence on stream ecosystem functions? What are the impacts on macro-invertebrate richness? What is the influence of urbanisation on groundwater recharge? Only the UNESCO Urban Water Series also draws conclusions for urban planning and could serve as a useful example for more broadly addressing governance issues.

3. **Sustainability approaches.** While the analysis of urban metabolism has been established as an appropriate approach for measuring flows, it also paves the way for assessing the sustainability of cities. With the sustainability concept, the normative aspect of how a city’s functioning should be based on resource flows and how these flows should be changed come into play. Thus the concept of urban metabolism can be used as a guiding principle for designing more sustainable cities (Codoban & Kennedy, 2008). Positive metabolism processes (i.e. those with decreasing resource flows) are distinguished from those that threaten the sustainability of cities (i.e. those that are characterised by increasing resource use) (Kennedy, Cuddihy, & Engel-Yan, 2007). The sustainability-oriented approaches of urban metabolism reveal a stronger focus on management aspects, e.g. control engineering (Beck, 2005). This implies the inclusion of stakeholders in decision-making processes. Thus, it reveals a closer relationship with regard to governance transformation.
4. **Sociological approaches** consider water as a means to exercise economic and societal power. Water has worked to either foster urban cohesion or generate new forms of political conflict. The sociological approaches focus on the way in which shareholders and stakeholders are included in or excluded from decision-making, oligopolistic supply structures, or the marketisation of goods such as water etc. (Gandy, 2004). In general, these considerations point to societal developments that include the coercion of powers, while governance structures and the transformation of governance structures are not explicitly addressed.

The results from the SCOPUS analysis show that up to now not much research addresses the link between urban metabolism and water explicitly. Overall it becomes evident that the research on urban metabolism is still a developing field.

Absolute Numbers	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Urban Metabolism	2	1	3	2	0	5	2	13	7	11
"Urban Metabolism" AND "Water "	0	0	1	1	0	1	0	4	5	2
"Resource Use" AND "Water"	48	49	39	55	41	156	79	73	79	110
Industrial Ecology	33	42	49	34	59	34	73	95	89	88
"Industrial Ecology" AND "Water"	1	5	4	3	4	4	9	13	14	12
"Urban Water"	59	42	58	67	67	117	87	131	171	153

Table 5: SCOPUS analysis search results (absolute numbers of studies): keywords associated with “urban metabolism”.

Summing up the review of relevant literature, one can draw **four conclusions**:

1. A number of studies on urban metabolism do exist. However, they are small in number and cover only a few cities worldwide. Due to the fact that the concept is relatively new, there are rare examples of urban metabolism. Furthermore, from the review of these studies it becomes obvious that the concept of urban metabolism is rather diverse. Interpretation issues are prevalent due to a lack of common conventions.
2. In many cases it is not water that is addressed but the broader set of resource flows (including energy, food, materials, CO2, etc.). When focussing on water it becomes obvious that the number of studies is even smaller.
3. Most studies aim at a better understanding of the environmental impacts of urbanisation processes. While this descriptive perspective has its merits, it is not clear whether and to what degree urban metabolism can be applied within decision-making tools and whether the concept can be fruitfully used to steer resource flows in urban agglomeration. In other words: there is a lack of action-oriented knowledge ("Handlungswissen").
4. Closely related to the previous aspect: governance issues are rarely addressed in existing studies. The concept of urban metabolism is mainly applied by the natural sciences, while the social sciences dealing with governance issues do not – or only rarely – participate in this research.

These conclusions lead to recommendations for developing the application area as a research area.

4.2.2.2 Recommendations for Developing the Research Area

The proposed research area "From Wastewater Treatment to Urban Metabolism" should focus on the emerging concept of urban metabolism. It should address urban water issues in their entire breadth and depth. The project should transcend the traditional focus on centralised wastewater treatment. Instead, the ingoing and outgoing water flows between the city and rural areas should be analysed in order to develop sustainable (i.e. environmentally effective, cost-efficient, and socially acceptable) solutions for urban water management. This includes new and innovative forms of (decentralised) water technologies that are to be developed against the background of future needs.

It is recommended to set the focus of the water metabolism research area on two aspects:

- Firstly, research should contribute to the **evaluation and interpretation** of ingoing and outgoing water flows, i.e. not only the (positive) description but also the (normative) assessment of water flows should be addressed. This requires (a) the identification and development of suitable indicators as well as relevant criteria for assessing water metabolism. As the development of relevant criteria has to be based on inhabitants' preferences, the inclusion of stakeholders in this process is imperative.
- Secondly, research should focus on **urban governance processes** in order to develop an understanding of the possibilities (and constraints) of steering and influencing urban metabolism. This requires the analysis of the relationship between governance structures and their impacts on resource flows. Typical research questions include: Does a centralisation of responsibilities lead to a centralised infrastructure system? What is the role of upper-governmental grants in selecting the type of infrastructure? Do neighbourhood-oriented solutions (closed water cycles,

decentralised technologies, etc.) reduce resource flows? What is the role of participatory decision-making processes? What are the prerequisites for improving the water metabolism (in the sense that less water-related resources are consumed)?

The research area could consist of **one or several projects**. The projects should include relevant case studies and focus on (1) the development and interpretation of indicators and criteria, and (2) the understanding of the relationship between urban metabolism and urban governance. The research area could also consist of one over-arching “meta-project”, e.g., in the form of a “synthesis project”, and several “sub-projects” conducting case studies. As urban metabolism focuses on dynamic change processes within urban areas, the projects should include a certain time span in order to be able to explain changes in urban metabolism – in this respect they should be dynamic instead of static.

There should be **no regional (geographical) focus**. Research should be based on “good” case studies that can be conducted in “mature” urban regions of the developed world or in urban agglomerations of the developing world. However, applicants should carefully explain the choice and the relevance of the chosen case study.

The research should be **inter- and transdisciplinary** in nature. The interdisciplinary approach stems from the necessity to include natural scientists as well as social scientists in the research. The social scientists must not necessarily be historians but should include those disciplines in particular that are suitable to address governance issues. The transdiciplinary approach is required because the criteria for evaluating urban metabolism (e.g. with regard to sustainable development) have to be developed jointly with the inhabitants that are concerned.

4.2.3 Application Area 3: From Flood Protection to Resilient Regions

Flood protection has been characterised by keeping the water out of the landscape and attempts to control river flows. In order to reduce flood hazards, rivers have been regulated and dikes have been built. This leads to reduction of floodplain biodiversity and a reduction of benefits provided by floodplain services like water retention resulting in increased peak flows. At the same time more assets are build in the flood plain. This leads to a higher likelihood of severe flood damage in case of flooding events which imposes further pressure on flood protection and building of higher dikes. The whole system is also vulnerable to climate change. The sensitivity to an increase in extreme flood events is high and adaptation options are reduced due to the path dependence. Such path dependence is not only manifested in large investments in long-lived infrastructure but also in the whole governance structure that has coevolved with a certain flood management paradigm.

Some countries particularly threatened by climate change, e.g. the Netherlands, have started to implement a new paradigm – more room for the river and living with water. Investment in natural capital and ecosystem services can reduce the vulnerability to climate change by building adaptive capacity. Well-functioning watersheds and intact floodplains and coasts provide water storage, flood control and coastal defence. They are ‘natural infrastructure’ for adaptation (Smith & Barchiesi, 2009). In the centre moves a more holistic view on resilient landscapes where water and water related services are an integral part of the landscape. Such changes pose major governance challenges. How to set goals and define what are resilient landscapes? Which kind of landscape services should be given priority, how to deal with conflicting use interests? How to reallocate water from the current use patterns? How to change land-use and regional planning processes?

4.2.3.1 Gaps in Scientific Knowledge and Potential to Achieve Scientific Breakthroughs

Despite change in public and political discourse and the increased awareness for radical changes in flood management practices these topics have only received limited attention in science up to now. As Table 6 shows the topic of flood management and vulnerability has attracted increasing attention also related to climate change considerations. Publications on room for the river are even more numerous than publications that adress explicitly processes of change (paradigm shift, transition, transformation).

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Flood management AND paradigm shift	1	0	0	0	3	0	1	2	3	4
Flood management AND resilience	4	2	0	3	5	5	5	8	12	13
Flood management AND vulnerability	20	13	24	13	16	27	12	21	42	47
Room for the river	12	18	17	17	16	31	26	25	28	30
Flood management AND (Transition OR Transformation)	7	8	6	9	4	13	9	11	11	19

Table 6: SCOPUS analysis search results (absolute numbers of studies): keywords associated with "flood management".

Despite change in public and political discourse change in management practices is very slow. Such inertia can be explained by the radical changes in the management regime that are needed to realise the postulated paradigm shift. Arguments have been put forward that implementation of integrated and adaptive flood management strategies and the reduction of the trade-off between flood protection and floodplain restoration can be achieved by taking into account ecosystem services of flood plains and by moving towards multi-functional dynamic landscapes (Pahl-Wostl, 2006; Smith & Barchiesi, 2009; Opperman *et al.*, 2009). As highlighted by Pahl-Wostl (2006), efficient integration requires processes of social learning since fundamental changes are needed in the governance structure. Elements of management regimes such as technical infrastructure (e.g. large technical infrastructure for flood protection), citizen behaviour (e.g. expectations regarding safety in floodplains, risk perception) and habits, and engineering rules of good practice are often mutually dependent. In many cases they have co-evolved over a long period of time. Such mutual relations can develop into pathological path dependence, so-called lock-in situations with the effect that changes towards new resource management schemes are blocked and require collective learning and decision making processes (Pahl-Wostl, 2002). To escape lock-in, actors need to learn to recognise how their own frame of reference influences and constrains their thinking and that other legitimate frames of reference exist. Such negotiation processes are complex and need to embrace actors from different levels. Experiences from the Dutch 'Room for the River' programme show that failure to resolve conflicts about controversial measures may put a whole programme at risk (Roth & Warner, 2009). Available analyses are to draw more general conclusions and factors that influence success of failure of such processes. Learning and negotiation processes gain more and more in importance since climate change has increased the awareness for the need for change towards flood management strategies that can better deal with uncertainty and surprise.

What strategies and governance arrangements are needed in water management to take into account not only existing uncertainties but also the possibility that some uncertainties about future conditions may expand as climate change progresses?

When adaptation to flood situations is necessary it is relatively easy to adapt the tools for disaster reduction management to also deal with future climate situations. There is however one serious issue: uncertainty. When 'normal' floods can be treated as a statistical phenomenon, under climate change conditions the past is no longer the predictor for the future). This increased uncertainty is a characteristic of the whole area of climate change research and policy (Huntjens, 2010, in press). Thus, the overall question mentioned above should be combined with developing methods for dealing with uncertainties in decision-making (e.g. long term scenario analyses, risk assessments, vulnerability assessments). A first step to deal with it always includes a scenario analysis leading to 'possible futures', not 'probable futures' as in statistical analysis. These scenarios have to be downscaled to the level of the system that has to be adapted to climate change. For climate change and water in Europe e.g. this is done in a project called SCENES[4]. Both steps, the scenarios and the downscaling, introduce large uncertainties. There is no way to make these disappear: they have to be dealt with. Hence, developing methods for dealing with uncertainties in decision-making (e.g. long terms scenario analyses, risk assessments, vulnerability assessments) are regarded as a key research area at various research institutes in Europe but also outside Europe, notably in the United States and Australia. Especially in developing countries poverty and vulnerability to disasters are closely linked. (Brauch *et al.*, 2008) The poor are disproportionately affected by disasters (GFDRR, 2008), due to their lack of assets with which to smooth consumption and respond to catastrophic events. With urbanisation, and agricultural modernisation, more and more economic activities are taking place in seasonally flooded plains, putting more people and infrastructure at risk (Lebel & Sinh, 2007). It is expected that this exposure will increase. Given increasing uncertainties new methods have been explored to reduce vulnerability by diversifying risk (Arts, Dicke, & Hancher, 2008).

4.2.3.2 Recommendations for Developing the Research Area

- Flood management is moving towards a new integrated and adaptive paradigm – at least at the level of discourse and policy but not yet at the level of practical implementation. Required are comparative analyses on the role of this multi-functional landscape paradigm in promoting change towards integrated and adaptive flood management and in identifying barriers that prevent change.
- The change in paradigm implies a shift in the role of actors at all levels from local to regional and global and a need for fine-tuning centralised control with bottom-up approaches.. It is recommended to conduct a multi-level analysis of the diffusion of the new flood management paradigm and governance styles and the role of actor networks in these processes.

4 Finland’s environmental administration website (last accessed on July 02, 2010): `http://www.environment.fi/default.asp?contentid=360595&lan=EN`

- Europe offers a fascinating opportunity to study the combined implementation of innovative water policy over the next decade. Member states have to implement the Water Framework and the Floods Directive in a coordinated way taking into account potential impacts of climate change. Comparative analyses of the implementation process in different countries and basins, the influence of governance systems and contextual factors on success of implementation and degree of innovation.

4.2.4 Application Area 4: Accepting the Limits: Building Resilience in Water Scarce Regions

At the global scale freshwater resources are not yet scarce. However, their uneven distribution at different scales (among world regions, countries, different social groups in a river basin, different kinds of uses) can provide multiple sources of tension. The 3rd World Water Development Report launched during the 5th World Water Forum 2009 shows alarming trends, (e.g. in water shortages and detrimental impacts on ecosystems and human development). Already now consequences of overexploitation of water resources are severe in many locations. The use of surface water for irrigation has lead to the disappearance of the Aral Sea. Many rivers do not reach the sea anymore (e.g. Colorado). Wetlands and protected Ramsar sites have disappeared (e.g. Orange, Guadiana, Guadalquivir). Future prospects are aggravated by climate change which will intensify looming water crises (Bates, Kundzewicz, Wu, & Palutikof, 2008).

Different kinds of management strategies are possible to reduce water scarcity. One may distinguish four kinds of approaches of increasing complexity and increasing difficulty to be implemented.

1. Development of further supply options: In case of crises the development of further water resources has often been sought as solution - building of desalinisation plants, interbasin water transfers etc. This has increasingly encountered limits though. Development of water resources may be quite expensive with increasing marginal costs. Interbasin transfers have become unpopular due to unknown environmental effects and projects have thus been blocked by resistance in the population (e.g. Ebro transfer in Spain).
2. Conservation of available supply: Despite water scarcity the use of the resource is often not efficient. The efficiency of using water for certain purposes may be increased by technical innovations or improvement of practices (e.g. irrigation). Such changes may still be quite straightforward to implement. However, often major changes in the overall governance system (e.g. institutional setting) are required.
3. (Re)Allocation among competing uses: Existing patterns of distribution among competing uses (e.g. environment, agriculture, households) are often unsustainable from a long-term ecological, social and even economic perspective. The (re)allocation of scarce water resources among different uses is a governance problem and cannot be solved by technical means.
4. Transformation and transitions towards sustainable, adaptive and integrated water management regimes is the most demanding of all strategies. Hardly ever current water use and land use and development patterns come under scrutiny. However, prospects of climate change strongly suggest that such fundamental changes may be required.

In particular (re)allocation and transformation of governance and management regimes pose serious governance problems. How to govern water allocation in an adaptive and sustainable way? How to govern change towards a more conscious water use that accepts also limits and takes precautions to avoid catastrophic crises in cases of extreme drought and shifting precipitation patterns due to climate change?

The strategy that should be chosen for dealing with water scarcity depends on the nature of the problem. If water scarcity is mainly a problem of mis-allocation and efficient use strategies to improve allocation are appropriate. However, if allocation is a problem of having exceeded absolute limits major structural transformation in land and water use patterns may be required.

4.2.4.1 Gaps in Scientific Knowledge and Potential to Achieve Scientific Breakthroughs

Has the scientific community come up to these challenges? Table 7 shows the results from a SCOPUS analysis of the number of publications on different topics related to water scarcity. One can note an increasing attention for climate change. Also work on governance shows a clear growth trend. Little efforts are devoted to analysing the role of resilience or adaptive capacity and system transformations in the context of water scarcity. The number of publications on these topics has remained at a low level over the past decade with no clear sign for an increasing trend.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Water scarcity	98	123	120	129	127	161	192	232	298	318
Water scarcity AND governance	0	5	3	1	1	2	4	7	5	16
Water scarcity AND climate change	7	5	6	8	19	9	12	19	34	52
Water scarcity AND resilience OR adaptive capacity	0	0	2	1	3	0	3	4	3	5
water scarcity AND (Transition OR Transformation)	6	2	4	3	2	5	5	7	8	11

Table 7: SCOPUS analysis search results (absolute numbers of studies): keywords associated with "water scarcity".

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Water allocation AND governance	1	3	0	0	4	6	3	7	5	21
Water allocation AND climate change	15	9	13	9	14	18	20	24	29	64
Water allocation AND resilience OR adaptive capacity	1	4	2	6	6	5	1	6	17	15

Table 8: SCOPUS analysis search results (absolute numbers of studies): keywords associated with "water allocation".

In the following recent trends in research and the major gaps are analysed in more detail with a focus on (re)allocation and transitions/transformations in particular in the context of adaptation to climate change and building adaptive capacity to deal with uncertainty and surprise.

Assessing the inherent characteristics of institutions to stimulate the adaptive capacity of society to respond to water scarcity and in particular the impacts of climate change

Institutions may enhance but also constrain the adaptive capacity of society and its ability to respond to the climate change challenge. Adaptive capacity is defined here as the ability of a resource governance system to first alter processes and if required convert structural elements as response to experienced or expected changes in the societal or natural environment (Pahl-Wostl, 2009). Important open questions refer to the assessment of the capacity of institutions to adapt to new circumstances and the way in which institutional arrangements can enhance that capacity. Water markets are perceived as flexible institutions responding to increasing scarcity by prize signals. However, a quite inflexible step is the allocation of fixed water rights as basis for the establishment of a water market. Furthermore, water markets are only effective when water is regarded as an economic good. Basic water supply essential for survival may be regarded as a human right which precedes economic considerations. To gain an understanding of the underlying processes of climate change adaptation as regards trust building, conflict resolution and pursuits of social justice among parties differentially vulnerable to droughts has so far not been explored in detail. Available evidence suggests that diverse institutional settings such as a combination of markets, bureaucratic hierarchies and network governance perform better than either of these governance modes in isolation (Pahl-Wostl, 2009).

Understanding transitions and adaptation strategies as multilevel governance processes and cross-scale interactions

A key challenge for policy-makers is how best to integrate important 'bottom-up' processes of learning with 'top-down' high-level policy strategies and visions. Strategies should stimulate and support pro-active adaptation responses at higher levels, whilst retaining the flexibility and robustness necessary for enabling the development, testing and implementation of measures at the local scale. Hardly any research programmes address these issues. Horisontal and vertical integration is also an exception in scientific research. Scholars focus on levels and sectors rather than analysing multi-level governance structures and cross-scale interactions. The need for better understanding of cross-scale interactions in natural resource governance is put forward by many scholars (e.g. Berkes, 2008; Cash *et al.*, 2006; Ostrom, 2005). Such cross-scale interactions also affect how social networks influence governance processes. It could therefore be of great value in researching natural resource governance processes ranging from the local to the global thus enabling understanding of various factors driving global environmental change.

How to ensure the integrity, accountability and legitimacy of governance during processes of transformation and adaptation to climate change?

Integrity and accountability are critical to good governance of water resources and services (UNDP Water Governance Facility, 2009). Ensuring the accountability and legitimacy of governance is particularly important in times of major transformations. The more regulatory competence and authority is conferred upon larger institutions and systems of governance - especially at the global level - the more we will be confronted with questions of how to ensure the accountability and legitimacy of governance (Biermann *et al.*, 2009). Corruption has been identified as one of the major factors impacting on efficiency and effectiveness in the water sector (WIN, 2010; Report Transparency International, 2008). It can hardly be expected that the situation will improve over time periods when climate change and water scarcity challenges demand action. Hardly any systematic analyses are available on how strategies can be developed that take into account the cultural and political realities and constraints in a country. Such strategies need to be pragmatic in the short-term but should support a transition of the governance system as a whole in the long-term. What are the sources of accountability and legitimacy in water governance? What are the effects of different forms and degrees of accountability and legitimacy for the performance of governance systems?

What are appropriate economic instruments taking into account environmental justice and equity?

Perhaps the best way to utilise water to the best and most valued uses is to put a price on water, and construct appropriate tariff structures to meet different social, political and economic goals in different situations. It has been argued that price policy can help maintain the sustainability of the resource itself: when the price of water reflects its true cost, the resource will be put to its most valuable uses (Rogers & Hall, 2003). Thereby, and assuming the poor can pay for such services, water pricing could contribute to adaptation and, for instance, if resources become scarce and water use is stabilised or reduced. Furthermore, if water resources are managed in an integrated fashion where the economic, legal and environmental aspects complement each other, increased prices can improve equity, efficiency and sustainability of the resource (Bakker *et al.*, 2008). Thus in the future, water pricing mechanisms can be used to send a scarcity signal and help balance supply and demand.

Water markets have been strongly promoted in supporting changes in water use patterns and in the reallocation of water rights. Incentive-based water rights acquisition and transactions have emerged as a market-oriented policy approach to reallocate water resources from existing uses to enhance the provision, regulation, and sustainability of freshwater ecosystem services (Garrick *et al.*, 2009). Due to limited experience and work on this issue major questions are yet open regarding the appropriate design of such markets (Slaugther, 2009).

One of the main challenges of water governments is: how to finance climate change adaptation plans, operations, infrastructure and projects? The last few decennia new forms of finance scheme and structures have become available and are now commonly used (Bossert, Meuleman, Weber, & Zwennes, 2006). These modern forms, finance schedules and structures are often known as public-private partnerships (or PPP's). Within the context of climate change adaptation PPP's might enable the public sector to spread the cost of the investment over the lifetime, in contrast to traditional financing where the public sector is required to provide capital, while the benefits will come much later and are mostly uncertain. Furthermore the presence of corruption may jeopardise effectiveness of major investments (cf. as well previous paragraph). Making available large sums of financial resources may provide wrong incentives – maximising the instream of financial support in the short term rather than developing economically, socially and environmentally sustainable strategies.

4.2.4.2 Recommendations for Developing the Research Area

It is recommended to develop the research area related to governance of transformation in the context of water scarcity by focusing on the following issues:

- Comprehensive analyses of governance systems with an emphasis how they influence allocation patterns, water scarcity and conflicts between different water uses are largely missing. Comparative multilevel analyses of governance systems are needed to provide a scientific base for deriving policy recommendations on how to improve allocation patterns taking into account a wider range of institutional and technical options for re-allocation rather than focusing on one level and one dominant design (e.g. large scale water transfer between rivers rather than improving water use efficiency and effectiveness at local and regional scales). Emphasis should also be given to the combination of different governance modes – formal regulatory frameworks, market based approaches and negotiation and learning processes in networks. Another important aspect is the analysis of factors and management strategies (i.e. adaptive management) that increase the adaptive capacity of a governance system and its ability to deal with uncertainty and surprise.
- A crucial step in developing strategies to deal with water scarcity and emerging threats from climate change is the initial framing of the problem: is it mainly an allocation problem among existing water uses with a need to improve efficiency, effectiveness and fairness or is the problem a severe over allocation of a limiting resource with the need for a radical change in water use patterns. Research should analyse how and by whom the problem has been framed, if and how scientific knowledge has been taken into account, if trends of reframing can be observed and how the institutional context influences these kinds of processes. Analyses should identify which kinds of governance systems (are expected to) support processes of learning and reframing, the development of innovative strategies and the acceptance of limits.
- A third stream of research that builds on the other pillars should analyse how to support change and a transformation towards sustainable and adaptive water use patterns. Such research needs to include historical studies of responses to severe water crises and if and how they triggered change. Analyses need also to include future studies and the development of tools for monitor change and for supporting an adaptive management of change processes.

4.3 Synthesis

4.3.1 Potential According to the Four Evaluation Criteria

4.3.1.1 Gaps in Scientific Knowledge and Potential to Achieve Scientific Breakthroughs

Governance of the transformation of human-technology-environment systems has proven to be a core concern in all the four thematic areas explored in more depth and in the whole water sector in general. At the same time this topic has received limited attention in the scientific community up to now which can largely be explained by the fact that the theme requires a systemic approach and collaboration of a wide range of disciplines. Given the scientific and political interest in the theme and the absence of visible international research programmes dealing with such issues the theme has the potential to open up an internationally visible and innovative research field and establish a leading role of the German/European community.

In the context of RESCUE[5], a foresight study of the European Science Foundation, the theme of system transitions and governance of transformation has also been identified as being one of the primary areas where scientific breakthroughs are urgently needed.

However, success will also depend on a good design of a research programme. What is needed are large scale comparative analyses that allow deriving general insights from a wide range of case studies instead of producing fragmented empirical evidence from case studies that cannot be compared.

4.3.1.2 Science-Policy Interplay

Despite of claims for integration policy implementation is still predominantly sectoral. Hence the identification of more focused application areas will facilitate the link to direct implementation. At the same time the embedding in a wider context will facilitate raising awareness for an integrated approach. The need for cross-sectoral collaboration has received strong emphasis due to climate change adaptation programmes. The European Commission commented on the provisions of European Water Policy Frameworks to fulfil the requirements identified for meeting the challenges posed by climate change adaptation. Figure 21 shows an excerpt of the document. The document concludes that both the European Framework and the Floods Directive require a cross-sectoral approach also needed for climate change adaptation. Furthermore the implementation of the two Directives must be coordinated which again supports an integrated approach. The CIS guidance document on climate change makes also strong claims on the need for adaptive and innovative approaches. Hence policy frameworks supporting innovative strategies are in place. However, barriers may be more identified at the implementation level. The broad governance approach adopted by the programme will be able to analyse possible policy –

5 Responses to Environmental and Societal Challenges for our Unstable Earth (RESCUE): http://www.esf.org/rescue

implementation gaps and provide recommendations how to improve them that can directly feed into policy implementation.

The themes addressed are of major concern in most countries in the world. Many countries have put into force innovative regulatory frameworks over the past decade and struggle now with implementation (e.g. Australia, South Africa, China). The proposed programme will offer excellent possibilities for international exchanges.

every six years. This flexible management framework is well-suited to managing adaptation to the impacts of climate change as it will enable new information on the impacts of climate change and the measures necessary to adjust to be incorporated into the revised river basin management plans. The requirement under the Water Framework Directive for Member States to take a cross-sectoral approach to water management will also facilitate the necessary cross-sectoral action on adaptation and provide a framework for consideration of the relationship between the use and management of the natural environment (e.g. land) and the quality and availability of water resources. Further, the achievement of "good ecological status" for all waters as provided in the Water Framework Directive will contribute strongly to improving and maintaining biodiversity in the aquatic environment, as well as those ecosystems which rely on the aquatic environment. Work is on-going at a European level to

States to coordinate their flood risk management practices in shared river basins, including with third counties, and to avoid taking measures that would increase the flood risk in neighbouring countries. Co-ordination with the implementation of the WFD is required under Article 9 of the Floods Directive from the second River Basin Management Plan. The Floods Directive therefore provides a comprehensive mechanism for assessing and monitoring increased risks of flooding due to climate change and for developing appropriate adaptation approaches. The coordinated approach with the river basin management plans will ensure an overall effective approach and help avoid maladaptation measures.

Figure 21: Excerpt of a Commission document on climate change and water policy[6]

4.3.1.3 Relevance of International Policy Problem

The debate about the need for a paradigm shift and major transformations in the water sector is not new. It has moved up higher on the political agenda in recent years with increasing concern about climate change and the recognised need to increase flexibility and the adaptive capacity of water management. The urgency of the policy problem is expected to increase in the years to come since climate change has exposed existing vulnerabilities that have to be reduced by major transformations irrespective of the regional manifestations of climate change.

Replication from the literature on societal transitions (Geels 2002; Rip & Kemp, 1998) advocates the need for new governance arrangement to address this type of persistent problems. The fact that the policy problem is not emergent, has been identified decades ago and remained on the on the policy agenda, is a strong argument for a research programme with specifically focuses on governance approaches addressing transformation, transition

6 Commission Staff Working Document: “Climate Change and Water, Costs and Marine Issues“{COM (2009) 147 final} accompanying the White Paper “Adapting to Claimte Change: Towards a European Framework for Action”.

and policy innovation. Lacking such approaches, the issue is most likely to be persistent over the next decade and become even more urgent.

4.3.1.4 Suitability of Implementation in the German Scientific Community

There is critical level expertise and internationally visible scholars in the German community on all themes addressed. A strong input is required from the social sciences which is a critical factor for any such kind of programme since the current capacity of the social science community does not yet meet the huge demand for social science expertise. Such an internationally visible programme could make a valuable contribution in attracting more social science scholars to this field. Given the novelty of the field there does not exist an internationally leading programme yet and, as a result, the programme could have major international impact.

Both the GLOWA and IWRM projects have succeeded in building up successful collaborations between natural, social sciences and engineering. The BMBF funded Global Water System Project has established an internationally visible governance programme and an interdisciplinary community of governance scholars. Hence a new programme could capitalise on prior investments.

The results from the Scopus analyses indicate that a relevant research community on the governance of the transformation of infrastructures exist within Europe.. Relevant institutions in Europe are the Eindhoven University of Technology and Imperial College London. Relevant journals in these fields are international and not connected to Europe or Germany. Publications on institutional transplantation mainly originate from Delft University of Technology and also the single pioneering publication on infrastructures stems from this university.

A research base for a programme on governance of the transformation of infrastructures exists within Europe. The United Kingdom, Switzerland and the Netherlands are relevant partners while the position of German Universities in this field in not yet standing out. On the broader topic of governance of transformation, within Europe the universities of Manchester and Oxford are relevant partners.

4.3.2 Outline of a Research Programme

As outlined in Figure 22 the programme should be structured around a core module that coordinates the development of a shared conceptual framework and the establishment of a shared data and knowledge base. Without such an integrative framework the risk is large that no general insights can be derived. Such a core module would further develop a shared language / ontology for key terms. The language should be specific enough that data protocols can be derived as base for large comparative analyses. It should however be flexible and not impose one theoretical framework. It is important to experiment with different theoretical approaches and different analytical emphasis however in a way that results can be compared. It is recommended to develop links with scholarly communities that work on similar themes. One emerging group is the so-called SES (Social-Ecological Systems) club around noble prize winner Elinor Ostrom with several partners from Germany, the Netherlands, Sweden and Norway.

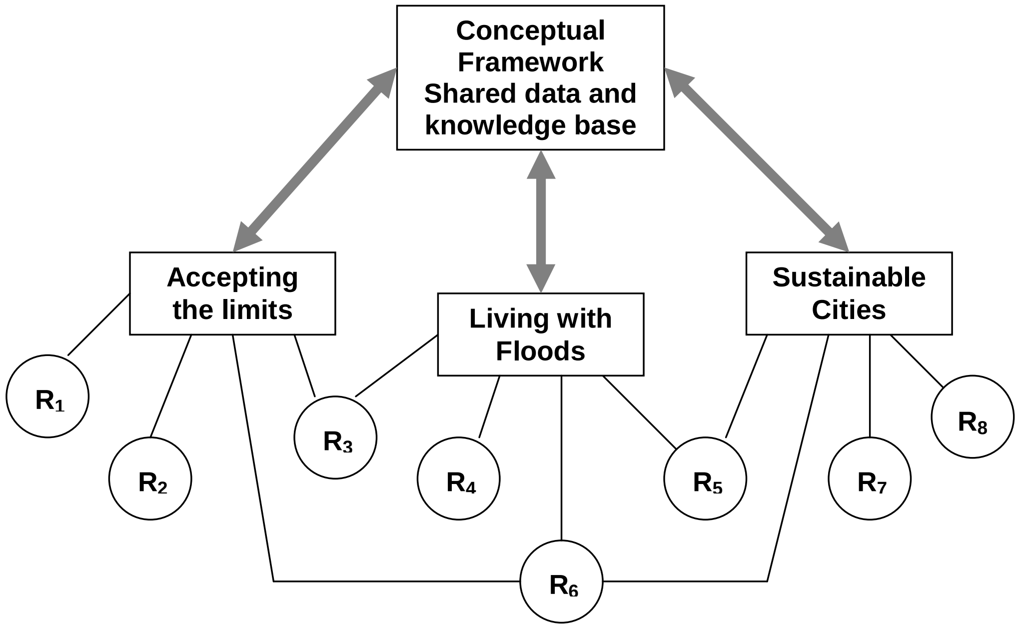

Figure 22: Structure of a proposed programme with an integrative core module, thematic areas and regions.

Three thematic areas are suggested:

- Accepting the limits around water scarcity
- Living with floods
- Sustainable cities (merging the themes urban metabolism and infrastructure transformation)

A case study approach is recommended with detailed studies in selected regions at several levels - regional, national and trans-boundary if appropriate. Regions may but must not address more than one of the thematic areas.

Regions should be chosen according to the urgency of the policy problem, presence of transformation processes and established contacts to regional and national stakeholders. Furthermore regions should be characterised by reasonable political stability. Some openness regarding regions seems to be desirable to support innovative ideas. Nevertheless a first recommendation on priority regions of interest is given in the following.

Regarding “living with floods” Europe is a very interesting study region. European water policy (European Water Directive, Floods Directive) requires and provides an enabling framework for change. Some European countries, in particular the Netherlands, are forerunners in this field.

Accepting the limits is of major relevance in drought prone areas where the situation is expected to become more severe with climate change: Australia, Southern Europe (Iberian Peninsula), Northern and Southern Africa.

China and India are interesting regions for studies combining all three thematic areas.

Such a research programme should also build strategic partnerships to relevant European universities and research organisations, in particular in Switzerland (ETH Zürich), the Netherlands (TU Delft) and Sweden (Resilience Centre Stockholm).

5 Theme Cluster 4: Manipulating Flow and Water Bodies for Managing Ecosystem Services

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5.1 Background

The theme cluster 'Manipulating flow and water bodies for managing ecosystem services' was identified to be one of the key themes during an international expert workshop on 'Future trends and research needs in water management' held in Osnabrück in February 2010. Based on initial literature reviews, originally, the theme cluster was titled 'Environmental flows, water related ecosystem services and trade-offs between human and environmental water needs'. The original title pointed out scientific gaps related to quantitative knowledge about the status and importance of fresh water ecosystems including ground water, implementation difficulties of environmental flow assessments, valuation of ecosystem services, the role of governance regimes, as well as the adaptation capacity of social-ecological systems. This served as a starting point for discussions at the aforementioned workshop and was further refined by a panel of experts. As a result recommendations for future research were made. According to the discussion outcomes, the key challenges of future research related to environmental flows are:

5. Functional linkages of natural and technical aquatic ecosystems
6. Process based understanding of hydrological-ecological linkages and feedbacks
7. Process based understanding of social-ecological linkages and feedbacks
8. Management tools for implementation of environmental flows

This expert judgement on future research needs and the relevance of this Application Area was elaborated upon by further assessments based on thorough literature reviews, which are presented below.

5.2 Introduction: Relevance of the Theme Cluster

The management of ecosystem services entails many challenges and requires integrated approaches that take into consideration both the ecological as well as the human dimensions to be able to address the multitude of underlying linkages and dynamics affecting ecosystem health and sustainable management.

The recognition of flow as a key driver of aquatic ecosystems has led to the development of the environmental flows concept. Environmental flows (EF's) describe the quantity, quality and timing of water flows required to sustain freshwater ecosystems in managed rivers (Dyson, Bergkamp, & Scanlon, 2003). Other concepts exist, such as minimum, or in stream flow. However such flow concepts lack a holistic view of the ecosystem and the services it provides, focusing on only one or a few aspects. The need to provide for EF's is well recognised among freshwater scientists. In 2007, the Brisbane Declaration on Environmental Flows was endorsed by more than 800 delegates from 57 countries (Brisbane declaration, 2007). The declaration announces an official pledge to work together to protect and restore the world's rivers and lakes through incorporating EF's in water management strategies. Environmental flows are defined in the Brisbane Declaration as the "quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihood and well-being that depend on these ecosystems" (Brisbane Declaration 2007). This definition highlights the importance of environmental flows for the preservation of ecosystem functions and services.

Changes in water bodies and ecosystems are not undesirable as such. In fact, changes in an ecosystem are often inevitable if not mandatory for its overall integrity (Holling, Gunderson, & Ludwig, 2002; Walker, Carpenter, & Kinzig, 2004). Ecosystems have adapted to site-specific water availability in terms of quantity, variability, and quality through a long-term evolutionary process. Fauna and flora heavily depend on the natural flow regime of rivers (Walker, Sheldon, & Puckridge, 1995; Power, Sun, Parker, Dietrich, & Wootton, 1995; Poff *et al.*, 1997; Bunn & Arthington, 2002; Lytle & Poff, 2004). Thus, the alteration of the key variable 'streamflow' induces profound changes in the ecosystem (Bunn & Arthington 2002; Poff & Zimmerman, 2010). The ecological-hydrological linkages and the management tools used for implementing the environmental flows concept are further explained in section 5.3.2 and 5.3.4.

The effects of alterations must be taken into consideration when managing ecosystems. Humans have a long history of making use of aquatic ecosystems and have altered these accordingly, having created technical aquatic ecosystems. These are closely interlinked with the natural ecosystems, which is starting to be recognised. Recent developments in environmental legislation in Europe, such as the EU Water Framework Directive require a more integrated approach to the management of hydrological catchments (Solimini, Ptacnik, & Cardoso, 2009). Similar approaches are advocated elsewhere (e.g. in Winter, Rosenberry, & LaBaugh, 2003). Holistic assessment and management of catchments therefore require a good understanding of interfaces between environmental compartments, especially in coupled natural-urban systems. The linkages between human and technical aquatic ecosystems are elaborated upon in section 5.3.1.

The 'ecosystem services' and 'ecosystem functions' concepts address the relation of physical or ecological systems and human values. Ecosystem functions (e.g. soil rentention) are the ecosystem processes that are used and valued by people, and thereby become ecosystem services (e.g. prevention of damage from erosion) (cf. De Groot, 2006; Termorshuizen & Opdam, 2009). The Millennium Ecosystem Assessment (MEA, 2005) placed ecosystem services into the categories *provisioning, regulating, cultural, and supporting*. Provisioning services are the most clearly recognisable services and provide direct products people can use, such as clean drinking water, or fertile land for agriculture and grazing. In respect to freshwater ecosystems, inland fisheries in developing countries may provide the only source of animal protein for rural people (Welcomme *et al.*, 2006). Regulating services like natural purification in wetlands and river ecosystems are often less obvious. The natural flow regimes of rivers support a variety of regulating ecosystem services, such as erosion, pollution, and flood and pest control (Poff *et al.*, 1997). Recreational, spiritual, aesthetic services are examples of cultural services of wetlands and water bodies. Water in general, and rivers in particular have a special value in the culture and spiritual traditions of indigenous peoples (Craig, 2007).

Supporting services are a necessary provision for all other ecosystem services. Their impacts on people are indirect or occur at longer time frames compared to other types of services. Examples are soil formation, nutrient cycling or climate regulation among others

(MEA, 2005). Hydrologic alterations also have an impact on these supporting services like nutrient cycling and biodiversity (Pringle, 1997; Richter, Braun, Mendelson, & Master, 1997).

When dealing with ecosystem functions and services, it must be borne in mind that other classifications of ecosystem services exist. Wallace (2007) criticises the MEA categories as being "*not a coherent set of services at the same level that can be explored and traded off in a decision system*" (Wallace, 2007, p. 238). For instance, food production (provisioning service) is an end of an ecosystem management process, while pollination (regulating service) is a means of service delivery. He also considers 'ecosystem function' as an ambiguous concept that is not required for the analysis of ecosystem services. Thus, Wallace (2007) proposes an alternative classification scheme that differentiates between ecosystem services, processes and structure.

Independent of how ecosystem services are categorised the reliance of humans on ecosystem services is widely agreed upon. This is most evident when looking at benefits that are of a material nature, for example, drinking water, fish and sea-food, as well as water for agricultural and industrial purposes. Albeit less visible the non-material services, such as climate regulation, pollination or nutrient cycling, are just as important for human well-being. Le Maitre, Milton, Jarmain, Colvin, Saayman, and Vlok (2005) point out how ecologists have stressed human dependencies on ecosystem services for decades. The nature of these dependencies and other social-ecological linkages are dealt with in more detail in section 3.3.3.

5.3 Application Areas

The following sections elaborate upon the individual Application Areas, which will form the basis for an overall synthesis. Some connections between different Application Areas will already become apparent, or will be explicitly referred to, within the coming sections. These are important in relation to identifying future research needs and, more specifically, making recommendations for future research programmes (see section 5.4.5).

5.3.1 Application Area 1: Functional Linkages of Coupled Natural and Technical Aquatic Ecosystems (Rural-Urban Linkages)

5.3.1.1 Introduction

There are numerous natural and technical interfaces in rural and urban water systems that link different compartments of the water cycle, such as surface water–groundwater, water–atmosphere, or water–soils. Other interfaces link natural and technical urban water compartments, such as wastewater–gas in sewer systems and wastewater treatment plants, or surface water–groundwater systems at bank filtration sites. Fluxes across interfaces are the exchange of water, dissolved substances, gases and energy between the different compartments. Interfaces are generally characterised by steep physical and biogeochemical gradients, disproportionately high numbers of micro-organisms, intense reaction rates and non-linear interactions, as well as feedback mechanisms between the different systems. The interfaces themselves are heterogeneous (i. e. there are hot spots), process intensities fluctuate (i. e. hot moments occur) and interface structure might be dynamic if biota is involved or the system is disturbed by external impacts. All these circumstances make fluxes across interfaces highly complex and they are much less understood compared to processes in single compartments. The state of the art in the field of fluxes across interfaces is characterised by considerable knowledge gaps.

Aquatic sediments act as dynamic sinks and sources in urban matter fluxes. Climate change, technical systems and management measures can change the function of interfaces in aquatic systems. Anaerobic processes in sediments should be investigated with focus on production of greenhouse gases and the remobilisation of nutrients and harmful substances. Water quality might be altered when water moves through highly reactive interfaces. For example, soil surfaces are an important interface linking atmosphere and hydrosphere. However, urban soils are drastically disturbed. Management of urban lawns and recreational lands are energy-intensive with a large input of fertilizers, pesticides and irrigation water. The free water surface is another interface linking atmosphere and hydrosphere. It acts as – partially bi-directional – exchange area of water (vapour), energy, (dissolved) gases (air, greenhouse gases) or nano-particles. The expected temperature increase due to anthropogenic climate change will affect the fluxes across interfaces via water surfaces, thus influencing the urban micro-climate as well as lake dynamics. There is a strong need to study these fluxes, the effects on the linked natural-urban water cycle, and the processes which control the fluxes.

All these interfaces were previously boundaries of environmental management units, but are now recognised to be important areas for cycling of energy, nutrients and organic compounds (McClain *et al.*, 2003), and exert significant control over catchment-wide pollutant transfer (Smith et al., 2009) and ecological health (Brunke & Gonser, 1997). Four examples for coupled natural and technical ecosystems are: a) Bank filtration and artificial groundwater recharge systems, b) self-purification of rivers, c) leaking sewer system, and d) the city-lake system..

5.3.1.2 The Relevance of Sub-themes within this Application Area

A better understanding of the interface processes in coupled natural and technical freshwater ecosystems is the key for reliable assessments of the influence of changing boundary conditions (climate change, demography, emerging substances, and new technologies) on natural and urban water cycles and aquatic ecosystems. Ecosystem management (e.g. river and lake restoration) is necessary to maintain or restore biodiversity at a landscape scale. To be effective, conservation efforts should be based on a solid conceptual foundation and a holistic understanding of river and lake ecosystems. Such background knowledge is necessary to re-establish environmental gradients, to reconnect interactive pathways, and to reconstitute natural dynamics responsible for high levels of biodiversity. The challenge for the future lies in protecting the ecological integrity and biodiversity of aquatic systems in the face of increasing pressures on our freshwater resources. This will require integrating sound scientific principles with management perspectives that recognise floodplains, groundwater and catchments as integral components of surface waters. Management should be based on sustaining, rather than suppressing, environmental heterogeneity (Ward, 1998). In that context, the following exciting research questions are to be addressed (e.g. Lovett, Jones, Turner, & Weathers, 2005):

- What are the physical and chemical boundary conditions that create ecosystem patterns and variations?
- What are the hydrologic processes that determine the variability in ecosystem structure and function?
- How do ecosystems interact with their aquatic and terrestrial environment?
- How does the water cycle interact with major biogeochemical cycles in ecosystems?

These topics, which often have been investigated in a more isolated approach, should be further developed in a strong interdisciplinary collaboration, including water and environmental engineering, limnology, hydrogeology, chemistry, microbiology, environmental economics, social sciences and sustainability science. Water issues always need a close connection and exchange between these fields of expertise (Royal Netherlands Academy of Arts and Science [KNAW], 2005). Therefore, the following four sub themes are identified to be representative for national and international research activities, including methodological issues. In the centre stands the land–water interface, connecting terrestrial and aquatic ecosystems, coupling natural and technical systems and the functional linkages of such interfaces.

5.3.1.2.1 Connectivity of Water and Landscapes

To date, most studies on land-water interactions have focussed on the one-way interaction from land to water by examining the transport of terrestrial derived materials to aquatic ecosystems (Walsh, Soranno, & Rutledge, 2003). Although there has been much research on the effect of land use on streams (Meybeck, 1998), lakes (Gächter & Wehrli, 1998), and wetlands (Lehtinen, Galatowitsch, & Tester, 1999) there are still significant knowledge gaps. Furthermore, to fully understand the complex interactions between aquatic and terrestrial ecosystems, aquatic ecosystems must not only be seen as receptor of human modification of the landscape, but also as potential drivers of modifications of the landscape (Riera *et al.*, 2001). It may be important to put more emphasis on developing stricter zoning around lake shorelines that limit development or find ways to increase the amount of lakeside vegetation. In seepage lakes, the close coupling of lakes and groundwater is often overlooked. It is quite difficult to quantify the amount and distribution of groundwater and substances entering lakes. Innovative measurement concepts are required for the groundwater–lake interface which is sometimes equivalent to a natural–technical interface (see also 'Introduction' of this section).

For streams, efforts have been put into place to preserve stream riparian and floodplain areas (see also Rockström *et al.*, 2009). Riverine floodplains are highly complex, dynamic and diverse ecosystems, and they are ideal systems to study ecological impacts of multiple stressors at the local, regional and catchment scale (Tockner *et al.*, 2007). Riverine floodplains are pulsed ecosystems with distinct flow, sediment, resource and thermal pulses and human modifications that truncate or amplify these pulses. That will have cascading effects on river-floodplain interactions by shifting the thresholds of connectivity, resilience or resistance - causing drastic regime shifts.

Riverine floodplains integrate and accumulate multiple stressors at the catchment level, as reflected by distinct catchment fingerprints. The river-aquifer interface may provide a very useful filter for controlling mass fluxes between groundwater and surface water systems. However, the interface is complex, has a spatially and temporally variable efficiency, is prone to clogging, but is also able to regenerate (Tellam & Lerner, 2009). If the processes occurring in this zone can be understood, it may be possible to harness its attenuation. It may even be possible in the future to improve properties and ecological status of this interface by active engineering or management, such as by river restoration, catchment management, or ecological manipulations. However, there is much work necessary before these possibilities may be fully realised, perhaps in several decades time, from developing the understanding of the processes through improving measurement and monitoring technologies to advancing modelling techniques.

Hydrological processes involve flows of matter and energy between different landscape components. Such connections between hill slopes and channel networks are sometimes understood at the scale of experimental sites, but not at larger catchment scales where many ecological processes are evident and management decisions are needed (Soulsby, Tetzlaff, Dunn, & Waldron, 2006; Tetzlaff *et al.*, 2007).

To understand the interactions between catchment hydrology and ecology, the concept of connectivity has obvious potential as a unifying theme where exchange of concepts and ideas can occur. Understanding ecological processes in the context of explicit catchment hydrological processes offers an existing research frontier in catchment hydrology, which has the potential to provide many important insights (Tetzlaff *et al.*, 2007). Opperman, Luster, McKenney, Roberts, and Meadows (2010) proposes a conceptual model that captures key attributes of ecologically functional floodplains, encompassing three basic elements: hydrologic connectivity between the river and the floodplain, a variable hydrograph that reflects seasonal precipitation patterns and retains a range of both high and low flow events, and sufficient spatial scale to encompass dynamic processes and for floodplain benefits to accrue to a meaningful level.

5.3.1.2.2 Riparian Zone Processes

At a smaller scale, the riparian or hyporheic zone – the transition zone between surface water in rivers or streams and groundwater – is a connecting compartment between surface water and groundwater (Hyporheic Handbook, 2009). It is a zone of intense biogeochemical activity and its ecological service is provided and sustained by the interaction of physical (e.g., transport of water and solutes), chemical (e.g., chemical reactions, sorption), and biotic processes (e.g., microbial transformation, bioturbation) (Brunke & Gonser, 1997; Sophocleous, 2002). In recent years, the interest in an improved understanding of exchange processes has substantially increased (Jones & Mulholland, 2000). This interest is driven by the recognition of the riparian zone as a compartment of utmost importance for maintaining the ecological function of running waters. This ecological function is affected by anthropogenic pressure on surface waters, for example by an increased probability of droughts and floods as an effect of climate change (Brunner, Simmons, & Cook, 2009). Exchange of surface water and groundwater with the riparian zone is closely linked to flow velocity, discharge, and water level in the river as well as to local and regional groundwater levels (Lewandowski, Lischeid, & Nützmann, 2009). The fluctuation of groundwater levels in the vicinity of streams and rivers is strongly coupled to hydrologic events like floods and droughts (Humphries & Baldwin, 2003). Riparian zones possess an unusually diverse array of species and environmental processes. The ecological diversity is related to variable flood regimes, geographically unique channel processes, climate shifts, and upland influences on the fluvial corridor. The resulting dynamic environment supports a variety of life-history strategies, biogeochemical cycles and rates, and organisms adapted to disturbance regimes over broad spatial and temporal scales. Innovations in riparian zone management have been effective in ameliorating many ecological issues related to land use and environmental quality (Naiman & Décamps, 1997).

Already in the earliest days of limnology, with regional limnology as the main field of research, it was quite clear that lake ecosystems also reflect the character of their catchment areas. The simple fact, that surface water and groundwater are carriers of solid and dissolved matter from catchment to lakes means that the shoreline should not be looked upon as a line of demarcation, but as a zone connecting terrestrial and aquatic ecosystems. A lake, together with its catchment area, constitutes the primary ecological and management unit of a river basin. Water bodies are the mirrors in which the original state - and recent care, management and mismanagement - of the catchments are reflected (Bjork, 2004).

5.3.1.2.3 Variability and Heterogeneity at Land-Water Interfaces

Heterogeneity of land and atmospheric processes contributes to all aspects of the hydrological cycle. Understanding the types and sources of this heterogeneity is a fundamental component of both theoretical and applied hydrology and ecology (Tague, 2005). Analysis of heterogeneity in hydrology seeks to characterise and, ultimately, explain spatial and temporal patterns in all of its forms and the pathways by which the water is transported and stored. This leads to the concepts of 'hydrologic landscapes' (Winter, 2001), and 'flowpaths as integrators of heterogeneity in streams and landscapes' (Fisher & Welter, 2005). During bank filtration, infiltration capacity depends on water extraction and hydraulic resistance of the bed sediments. Lake bed hydraulics may be especially affected by clogging, which is dependent on settlement of fine particles, redox potential and other factors. In the field, most of these processes are difficult to quantify. Responses to pumping across the sediment surface is often assumed to be linearly dependent on the hydraulic gradient only. However, this assumption was not adequate, and Wiese and Nützmann (2009) described the leakage coefficient as spatially distributed and also temporally variant.

In natural systems, the chemistry of floodplain water is a function of the source of the water, which is influenced by geologic and geomorphic features of riparian wetlands. However, anthropogenic disturbances may alter both geomorphic features and the natural balance of water mixing in the floodplain. Cabezas *et al.* (2009) studied riparian wetlands and characterised their water characteristics in one reach of the Middle Ebro River to assess the hydrochemical functioning of the system. Geomorphic characteristics of riparian wetlands were also analysed to interpret the results at broader spatio-temporal scales. Total dissolved solids, major ions (sulfate, chloride, sodium, calcium, magnesium, and potassium) and nutrients (nitrate, ammonium and organic nitrogen, and phosphate) depended upon the relations between surface and subsurface water flows. Seasonal changes and geomorphic characterisation indicated that a strong functional dependence of floodplain wetlands close to the main river channel exists, whereas most of the floodplain area remains disconnected from river dynamics.

Rates and reactions of biogeochemical processes vary in space and time to produce both hot spots and hot moments of element cycling. Biogeochemical hot spots are defined as patches that show disproportionately high reaction rates relative to the surrounding matrix. Hot moments are defined as short periods of time that exhibit disproportionately high reaction rates relative to longer intervening time periods. As has been appreciated by ecologists for decades, hot spot and hot moment activity is often enhanced at terrestrial-aquatic interfaces. Hot moments occur when episodic hydrological flowpaths reactivate and/or mobilise accumulated reactants. By focusing on the delivery of specific missing reactants via hydrologic flowpaths, a better mechanistic understanding of the factors that create hot spots and hot moments is needed (McClain *et al.* 2003). Such a mechanistic understanding is necessary so that biogeochemical hot spots can be identified at broader spatiotemporal scales and can be factored into quantitative models. The authors emphasise the need for further research to assess the potential importance of hot spot and hot moment phenomena in the cycling of different bioactive elements, improve our ability to predict their occurrence, assess their importance in landscape biogeochemistry, and evaluate their utility as tools for resource management.

Lakes, far from being homogeneous environments which we might expect, offer a rich and dynamic heterogeneity at multiple spatial and temporal scales that we are just beginning to understand. Starting with the centimetre scale pore water concentrations in lake sediments vary horizontally as well as vertically several orders of magnitude over a few centimetres (Lewandowski, Rüter, & Hupfer, 2002) due to hydrologic impacts of chironomids (Lewandowski, Laskov, & Hupfer, 2007). On a within-lake scale, a complex set of phenomena such as internal waves and stream intrusions leads to both horizontal and vertical heterogeneity. Within a landscape, lakes often differ from each other both in their average characteristics and in their inter-annual dynamics. In landscapes dominated by groundwater flow, there is often more heterogeneity in lake characteristics and response to climatic events than in landscapes where exposed bedrock leads to rapid horizontal transport of water (Kratz, MacIntyre, & Webster, 2005).

5.3.1.2.4 Managing Coupled Natural and Technical Terrestrial-Aquatic Interfaces

The water balance of a landscape is a formative element of the natural ecosystem, in which man intervenes in a variety of ways, both direct and indirect (German Research Foundation [DFG], 2003). River and lake restoration measures (e.g. aluminium addition to lakes, aeration of hypolimnetic water, river bank renaturalisation) are strongly connected to terrestrial-aquatic interfaces. The use of surface and/or subsurface water resources (e.g. for bank filtration and irrigation) is also related to these interfaces. Examples of the variety of measures that influence hydrological and biogeochemical processes at aquatic-terrestrial interfaces are presented in the following paragraph.

The construction of canals created new flowpaths that cut across historic stream channels, and the creation of artificial lakes produced sinks for fine sediments and hotspots for nitrogen processing. Further hydrologic manipulations, such as groundwater pumping, linked surface flows to the aquifer and replaced ephemeral washes with perennial waters. These alterations of hydrologic structure are typical by-products of urban growth and create distinct spatial and temporal patterns of nitrogen availability. Constructed wetlands that mimic natural marshes have been used as low-cost alternatives to conventional secondary or tertiary wastewater treatment (Thullen, Sartoris, & Nelson, 2005). They showed that effective water treatment function and good wildlife quality within a surface-flow constructed wetland depend upon the health and sustainability of the vegetation, another ‘interface’ in the context described here. Although floodplains support high levels of biodiversity and some of the most productive ecosystems on Earth, they are also among the most converted and threatened ecosystems and therefore have recently become the focus of conservation and restoration programmes across different countries and globally (Opperman *et al.*, 2010). These efforts seek to conserve or restore complex, highly variable ecosystems and often must simultaneously address both land and water management. Such efforts must overcome considerable scientific, technical, and socioeconomic challenges. In addition to proposing a scientific conceptual model, this chapter also includes three case studies that illustrate methods for addressing these technical and socioeconomic challenges within projects that seek to promote ecologically functional floodplains through river-floodplain reconnection and/or restoration of key components of hydrological variability.

As mentioned in the introduction, bank filtration and artificial groundwater recharge are typical examples for coupled natural and technical ecosystems. At a minimum, river or lake bank filtration acts as a pre-treatment step in drinking-water production and, in some instances, can serve as the final treatment just before disinfection. The main transformation (degradation) processes of diverse chemical compounds during this filtration occur at the surface water – groundwater interface sediments. Within the NASRI project (Berlin Centre of Competence for Water [KWB], 2005) a comprehensive biogeochemical process understanding has been developed. With the aid of modelling tools – used for water quantity and quality calculation and interpretation – principal transferability was achieved. These comprehensively integrated results serve as a “model” for identifying missing links in the coupling of natural and technical aquatic systems.

5.3.1.2.5 Summary

Four themes are of increasing interest for national and international research activities:

1. Connectivity of water and landscape
2. Riparian zone processes
3. Variability and heterogeneity of land-water interfaces, and
4. Managing coupled natural and technical terrestrial-aquatic interfaces.

The land-water interface may provide a very useful filter for controlling mass fluxes between groundwater and surface water systems. However, it is complex, having spatially and temporally variable efficiency, being prone to clogging but able to regenerate and also degenerate. If the processes occurring in this zone can be understood, it may be possible to harness its attenuation and in some instances flow-insulating capacity to very good effect. It may even be possible in the future to improve these properties and ecological status of this interface by active engineering or management, such as by river restoration, catchment management, or ecological manipulations. However, there is much work necessary before these possibilities may be realised fully, perhaps in several decades time, from developing the understanding of the processes through improving measurement and monitoring technologies to advancing modelling techniques.

5.3.2 Application Area 2: Process-based Understanding of Hydrological-Ecological Linkages and Feedbacks, with Focus on Carbon and Nitrogen Cycling

5.3.2.1 Introduction

Aquatic ecosystems are threatened by river regulation, diversion and over-abstraction of water, pollution, and spreading of exotic species. This does not only affect the aquatic ecosystems negatively, but also the ecosystem services these systems provide in terms of clean water, food production, pest and pollution control and so forth. Recognition of the escalating hydrological alteration of rivers and resultant environmental degradation has led to overarching policy frameworks, such as Integrated Water Resource Management (IWRM, Moriarty *et al*., 2004). It is well recognised by scientists that the structure and function of a riverine ecosystem is determined by temporal variation in river flows (Poff *et al*., 1997). To protect freshwater biodiversity and the goods and services it provides, rivers need to be managed in a way that mimic components of natural flow variability; magnitude, frequency, timing, duration, rate of change and predictability of flow events (Arthington, Bunn, Poff, & Naiman, 2006).

The concept of environmental flows has shifted from incorporating only the aquatic ecosystems dependence on flow regime to a more anthropogenic focus incorporating the human dependence on ecosystem services. '*Environmental Flows describes the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems'* (Brisbane declaration, 2007). Application Area 3 provides more details on the ecosystem services concept and socio-ecological linkages.

Ultimately the ecological condition in which rivers and their services to humans are sustained is essentially a socio-political decision. Ecosystem conditions may be determined by a negotiated and 'desired' environmental flow by various stakeholders or a desired ecosystem condition may be set (e.g. by legislation), and the flow requirement is the water regime needed to sustain the ecosystems in that desired condition. Incorporating environmental flows in water management allows for a more comprehensive, fair and sustainable utilisation of natural resources (Naiman *et al.*, 2002). Methods and tools for the participatory analysis, decision-making, and implementation of flow rules are presented in Application Area 4.

Addressing environmental flows is indispensable to achieving the objectives of IWRM. However, the knowledge on how to do this in practice is still inadequate, leading to insufficient flow prescriptions in managed rivers. Despite numerous studies on effects of human alteration of flow, and the scientific consensus of the importance of a natural flow regime, translating general hydrologic-ecological principles and knowledge into specific management rules remains a daunting challenge (Poff & Zimmerman, 2010). One reason for this is that more specific quantitative data on hydrologic-ecological linkages and feedbacks are in short supply.

Water for public supply, irrigation and industry are examples of direct use of water, whilst water for ecosystems provides benefits in an indirect way for people by supporting vital ecosystem services. The services maintained by ecosystems have real economic values that are generally neglected in management cost-benefit analyses. These values are linked to the products provided by ecosystems (e.g. fisheries) as well as the avoidance of costs related to declining profits, remedial measures, damage repair, and health care. Healthy aquatic ecosystems are also to be valued for their adaptability and greater resilience in the face of pollution threats and climate change. There are trade-offs in terms of benefits received between allocating water to direct and in-direct human uses. Addressing these trade-offs is necessary to maintaining the total long term benefits of aquatic systems.

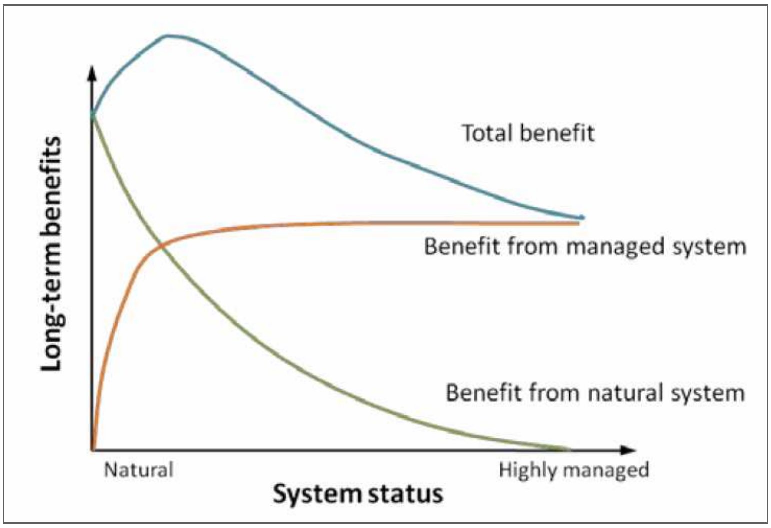

Figure 23: Trade-off between benefits from natural and modified systems.

Figure 23 shows that modifications of natural systems continuously decrease the indirect benefits of the natural system (green line). At the same time, benefits from the highly managed system increase (orange line). Benefits from highly managed systems reach a plateau at some point, while the benefits of the natural system decline to zero at some point. Total long term benefits can be calculated by adding the benefits of the natural and highly managed systems. The total rises to a maximum before declining. It is at this point that the balance between naturalness and level of management is optimised (modified from Acreman, 2001).

5.3.2.2 Recent Research Trends on Hydrological-Ecological Linkages and Feedbacks

Poff & Zimmerman (2010) did a thorough review of ecological responses to altered flow regimes. They found that good quantitative data of flow ecology relationships where generally lacking across organism groups. Some groups such as fish were better represented than others. They found no studies that reported primarily on ecosystem functional responses to flow alteration (e.g. riparian production, nutrient retention and cycling, stream metabolism, etc.), even though many ecological processes are clearly flow-dependent (i.e. Hart & Finelli, 1999; Doyle, Stanley, Strayer, Jacobson, & Schmidt, 2005). They conclude that this absence points to an obvious research gap when studying effects of flow alteration. A reason for this could be the often short-term, 'snapshot' nature of biological sampling done to document ecological change in flow-altered systems.

Riparian, floodplain and wetland productivity and hydrogeomorphology are linked to processes such as nitrogen retention and carbon storage and transport. The main driver behind these linkages is the flow regime (Tabacchi *et al.*, 1998). Given the importance of wetlands and aquatic ecosystems for the cycling of nutrients and carbon, it is important to understand what these linkages look like and how different water management options affect processes. Finally, methodologies for the assessment of hydrological-ecological linkages and feedbacks vary from simple rules of thumb to data-intensive computer models (O'Keeffe & Le Quesne, 2009; Poff *et al.*, 2010). While the former methods are often too simplistic for adequate assessment of flow-ecology relationships, the application of the latter requires resources that can not be provided in many parts of the world. The ELOHA framework is a recent approach to find a balance between level of detail and resource effectiveness by defining river typologies that allow flow assessment at the regional and national scale (Poff *et al*., 2010). The research gaps and trends mentioned above are elaborated below.

5.3.2.2.1 The Links between Hydrologic Regime and Riparian, Floodplain and Wetland Productivity.

Riparian productivity is often lower in rivers where flow is regulated (Jansson *et al.*, 2000). The main reason for this is hypothesised to be the lack of floods bringing nutrients to the riparian vegetation. For example flood frequency is important for the productivity and decomposition of plants. Padial and Thomas (1998) showed that floods, even of short duration, increase the decomposition rate and the nutrient cycling relative to dry conditions. Flow regime has an impact on growth response in riparian forests trees. Anderson *et al.* (2008) found a parabolic curve response to flooding, suggesting that there is an optimal flooding regime to promote growth. The relationship between riparian vegetation and flow regime may also differ between various functional groups (Robertson *et al.*, 2001).

5.3.2.2.2 Hydro-Ecological Links in Carbon Cycling

The capacity of wetlands to store carbon is drawing increasing attention around the globe (Lenart, 2009). Peat lands store 30% of the world’s terrestrial soil carbon (Chivers, Turetsky, Waddington, Harden, & McGuire, 2009). Leading experts and politicians alike argue that wetlands, in particular peat forming wetlands, should qualify as carbon credits in a global climate treaty, similar to that of forested land in the UN-REDD programme. There was a push for this before the COP15 meeting in December 2009, but such a programme was not adopted. A literature analysis showed a slightly increasing trend in papers that contained the search terms “wetland” and “carbon sink”, and “wetland” and “carbon cycling.

However the role of wetlands in carbon sequestration is not clear-cut (Bridgham, Megonigal, Keller, Bliss, & Trettin, 2006). Wetlands are also contributors of green house gasses to the atmosphere, primarily in the form of methane. Whether wetlands are carbon sinks or net contributors of green house gasses varies from site to site, but what this variation looks like is poorly known (Lenart, 2009). Information on this across regional gradients would add to the understanding of the role wetlands play in the global carbon cycle. There is also a need for further knowledge on how flow management and water allocation affects carbon sequestration within a watershed. A study on water table and temperature manipulations in an Alaskan fen suggests that draught will decrease ecosystem carbon storage, while inundation will increase it by stimulating plant growth (Chivers *et al.*, 2009). Methane and CO2 dynamics is also influenced by soil property (Altor & Mitsch, 2008) and vegetation type (Miller & Fujii, 2010). Increased knowledge on how the hydrologic regime links with CO2 sequestration and methane emission across larger spatial scales and between various types of wetlands would be a valuable addition to incorporate in flow management schemes.

5.3.2.2.3 Hydro-Ecological Links in Nitrogen Cycling

Human activities have disrupted the natural biogeochemical cycling and doubled the rate of nitrogen input to terrestrial systems (Vitousek *et al*., 1997). This has in many cases led to greatly increased nitrogen loadings in rivers, estuaries and oceans. Floodplains are important sites for denitrification and nitrogen retention and it is well known that constructed wetlands in the drainage area and riparian buffer zones can reduce the amount of nitrogen run-off that reaches the stream and estuary ecosystems. In monetary terms, denitrification and nitrogen retention is calculated to have a great net worth. For the Danube, nitrogen processing was estimated to respond to half the worth of all ecosystem services combined (Gren, Groth, & Sylvén, 1995). Wetland restoration and creation is increasingly being used as a means to protect against harmful run-off, but restoration of flood plains is lagging. It is estimated that 90% of flood plain forests have been lost in Europe and North America (Tockner & Stanford, 2002) due to flood protection measurements, damming and regulation of flow, and altering former floodplains to agricultural land.

Fluctuating water levels creates aerobic and anaerobic conditions that are effective for enhancing denitrification (Reddy & Patrick Jr., 1975; Groffman & Tiedje, 1988). Nutrient cycling and export in streams and rivers should vary with flow regime, yet most studies of stream nutrient transformation do not include hydrologic variability (Hall Jr., Baker, Arp, & Koch, 2009). It is not well known how alterations fo natural flow regimes affect floodplain denitrification (Gergel, Carpenter, & Stanley, 2005), especially over larger scales. Kadlec (2010) found that nitrogen removal was enhanced in wetlands maintained by water pumping when introducing hydrological events (pulsed flow) compared to steady state wetlands. Hunter & Falkner (2001) found that more denitrification occurred in forested wetlands where the natural flow regime is maintained compared to restored wetlands where the hydrologic regime had not been established. Gergel *et al.* (2005) simulated the effects of flood alteration through upstream dams and setback levees on a generalised flood plain, mimicking features typical for the upper Mid-Western US. They found that dams reduced nitrogen processing more than levees. Levees increased denitrification rates, but reduced overall denitrification through reduction in inundated area. A study on soil nitrogen cycling in riparian wetlands across a European climatic gradient found that water table elevation was the main driver of nitrogen cyling. Neither climatic factors nor vegetation type seemed to affect significantly denitrification rates (Hefting *et al.*, 2004).

Pinay, Clement, and Naiman (2002) raised some scientific challenges to improve our knowledge on the ecological consequences of changing water regimes on nitrogen cycling. These challenges mainly relate to cumulative impacts of regime changes, i.e. combination of changes in flow variables, scale of appraisal of these changes, and the relative impact of natural and human changes.

5.3.2.2.4 Methodological Framework for Environmental Flow Assessment at Large Scales

The threat of over-allocation of rivers is rising due to the accelerating pace of global and climate change (cf. Palmer *et al.*, 2008). Water management has to deal with an increasing uncertainty that demands innovative approaches to deal with societal pressure on ecosystems (Pahl-Wostl, 2007a). Understanding the linkage of environmental flow regimes to ecosystem functions and to environmental services, is a complex task that requires in-depth empirical research to generate reliable knowledge and flow standards. However, long-term scientific research is often not possible as resources are often limited, and water management demands timely results (Hanssen, Rouwette, & Van Katwijk, 2009). The use of 'rules of thumb' is one approach to come to quick results with limited resources. Flow standards are therefore calculated by using fixed percentages of flow components like the median annual flow, base flow, or surface runoff (e.g. Cullen, 2001; Smakhtin, Revenga, & Döll, 2004). These simplistic and static approaches are more and more criticised as they ignore the full complexity of the natural system and are not based on empirical research

(Richter *et al.*, 1996; Poff *et al.*, 1997; Lytle & Poff, 2004; Arthington *et al.*, 2006). Given the resource intensity of quantitative assessment methods, Poff *et al.* (2010) argue that a river-by-river assessment of environmental flows will not keep pace with global and climate change, even though methodological knowledge from individual case studies is advanced. They propose the synthesis of existing knowledge into a scientific framework for the assessment of environmental flows at larger scales, namely regional up to national scales. This generic approach comprises the identification of classes of natural rivers in a region based on ecological responses to flow alteration (cf. Arthington *et al.*, 2006). Impaired rivers are sorted in these classes by estimating the pre-disturbance flow metrics or applying landscape or climate characteristics. The framework builds on the notion that flow-ecological relationships are not necessarily exclusive to single rivers but may be applicable to rivers of a particular hydrological type, such as arid-zone or snow-melt rivers (Poff & Allan, 1995). A class represents a "management unit" and provides a guideline for the implementation of environmental flows based on empirical knowledge gained in other rivers belonging to the particular class. Quantitative relationships between flow-alteration and ecological response have to be developed along the gradient of natural to impaired river flow regimes in order to be able to set environmental flow standards. Thus, flow rules can be tailored to management goals about the status of rivers ranging from the preservation of natural flow regimes, to restoration of highly modified rivers (Arthington *et al.*, 2006).

5.3.2.2.5 Summary

Several gaps in scientific knowledge on understanding of hydrological-ecological linkages and feedbacks focusing on floodplain, wetland, and riparian productivity, and carbon and nitrogen cycling have been identified. The most important is how these processes vary with flow regime, and how human alteration of flow affects these processes. Most studies found were site specific or focusing on only one type of system.

A research programme that focuses on larger spatial scales and across different types of hydrological landscapes, modelling flow-ecology response relationships would serve as valuable decision support system in water management. Results from such a programme could also feed into a programme focusing on functional linkages of coupled natural and technical aquatic ecosystems (i.e. rural-urban linkages). Preferably, such a research programme would run over several years in order to capture not only spatial, but also temporal variability in flow, the driving variable. However, also smaller projects would add valuable knowledge in obtaining a fuller understanding how flow alteration affects these ecosystem services.

5.3.3 Application Area 3: Process-based Understanding of Social-Ecological Linkages and Feedbacks: How do Societies Depend on Ecosystem Services?

5.3.3.1 Introduction

In recent history there has been growing recognition of the benefits humans derive from ecosystem services (e.g. Baron *et al.*, 2002; Daily & Matson, 2008). By now the human dependency is a widely acknowledged fact and was reconfirmed by the Millennium

Ecosystem Assessment Synthesis Report in 2005, which highlighted the detrimental effects of ecosystem degradation on the services provided and, accordingly, on human society.

With increasing pressures on ecosystem services due to global change, especially population growth and climate change, there is the risk of growing imbalances, which need to be addressed (e.g. Jackson *et al.*, 2001). In a recent IUCN publication it is advocated to make use of natural infrastructure since intact watersheds, floodplain and coastal areas can contribute to reducing people's vulnerability and increase adaptive capacity through water storage, flood control and coastal defence. This forms the basis for reducing trade-offs and building resilience when combined with good governance and learning, whereas engineering solutions alone are not sufficient and can even have detrimental effects on resilience due to resulting environmental damage (see also Folke *et al.*, 2004; Folke *et al.*, 2002).

Adaptive management and governance of resilience are thus needed to restore degraded ecosystems so that these are capable of delivering essential services even when changes occur (e.g. Folke *et al.*, 2004; Adger, Hughes, Folke, Carpenter, & Rockström, 2005). Nelson, Adger, and Brown (2007) suggest a systemic resilience framework to analyse adaptation processes and identify policy responses. With this framework, they also go beyond the more common actor-centered approaches and link the social system to the ecological in order to identify the mechanisms of adaptation creating a learning environment. Consequently, a resilient social-ecological system may make use of crisis as an opportunity to transform into a more desired state (Folke, Hahn, Olsson, & Norberg, 2005). The importance of addressing future challenges in an integrative manner is also highlighted by other studies, e.g. in a development context (Brown & Lall, 2006), or with a special focus on the role of communities in ecosystem management (Fabricius, Folke, Cundill, & Schultz, 2007). Fabricius *et al.*, 2007 provide a synthesis of papers from a special issue titled "Strengthening People's Adaptive Capacity for Ecosystem Management and Human Well-being" categorising different types of communities in relation to how they cope with change. Results show that those communities able to improve their adaptive capacity can deal with challenges, trade-offs between short and long term effects on their well-being, and implement ecosystem management rules safeguarding ecosystem services.

According to Zehnder, Yang, and Schertenleib (2003), a fair distribution of freshwater between humans and nature is one of the major future challenges. It is evident that the social and ecological systems are closely intertwined and that a sound knowledge base and good understanding of the underlying processes and dynamics of social-ecological linkages are needed to arrive at sustainable ecosystem services management that equally caters for the human and environmental water needs.

5.3.3.2 Current State of Research

5.3.3.2.1 Understanding of Social-Ecological Linkages

The concept of ecosystem services aims at finding solutions to simultaneously conserve biodiversity and promote human well-being (Tallis, Goldman, Uhl, & Brosi, 2009). According to Braimoh, Agboola, and Subramanian (2009) an underlying assumption of the MEA (2005) is that due to the interconnectedness of environmental and human well-being, improvement of the former will lead to progress of the latter as well. However, this does not fully take into account the possible trade-offs. When making use of one ecosystem service others may deteriorate as a result.

Furthermore, Tallis *et al.* (2009) point out that only a few examples of successful win-win cases are known to date and that no guiding theories exist. According to Farber, Costanza, and Wilson (2002) the chances of achieving win-win situation are likely to become even scarcer when looking at it from a fully global perspective. To gain a better understanding of what is currently being implemented in the field in order to integrate conservation and development goals they analysed a total of 103 ecosystem service projects in over 30 countries. This explorative study purely documented and categorised what has been done within the scope of these projects in the context of developing countries and is only a first step in building up a knowledge base for better understanding specific social-ecological linkages. The actual outcomes of the implementation projects were not monitored by the researchers and only about a third of the projects monitor their own work.

Overall, despite their recognition many social-ecological linkages are not understood very well as they are very complex and information on the underlying dynamics and relationships are still lacking (e.g. Jewitt, 2002; Butler & Oluoch-Kosura, 2006; Carpenter *et al.*, 2009). This is also true for the ecological and social systems when looked at as separate entities. Various authors highlight that even though a lot of progress is being made, the ecological understanding of ecosystem functions and services is still limited (e.g. Kremen & Ostfeld, 2005; Daily & Matson, 2008) (see also section 5.3.2 – ‘Process-based understanding of hydrological-ecological linkages and feedback’). In a recent publication Bennet, Peterson, and Gordon (2009) address this lack of understanding and develop a typology of relationships among ecosystem services in order to drive forward research in this field.

In relation to the social system Butler & Oluoch-Kosura (2006) point out that access to ecosystem services is not equally distributed. But even in cases of sufficient access and use of available services, well-being is not automatically improved. Additional factors, such as income or the level of democracy, also play an important role in determining human well-being. Butler and Oluoch-Kosura (2006) argue that the ‘causality between ecosystem services and well-being is bidirectional’, which means that the state of society also influences the state of ecosystem services.

5.3.3.2.2 Managing Trade-offs Between Human and Environmental Water Needs: The Role of Governance

Understanding the causal relations among different ecosystem services as well as between the ecological and social system is essential for being able to manage trade-offs.

Based on different studies dealing with trade-offs Braimoh *et al.* (2009) provide an overview of the two main forms of trade-offs: spatial and temporal. Spatial trade-offs imply that through the use of one ecosystem service in a specific location another service is reduced or even lost in that same location or in the immediate surroundings. An example is the use of water for irrigation which limits the availability of water for other purposes. Spatial trade-offs also describe situations in which people in one area benefit from ecosystem services from a distant place, e.g. between rural and urban areas or between countries.

Temporal trade-offs often refer to intergenerational imbalances. Making use of ecosystem services to meet current needs may compromise the functioning of that and interlinked ecosystem services in future. Often the provisioning services are exploited in the short-term at the expense of long-term regulating or cultural services.

Falkenmark & Rockström (2004) stress those sustainable solutions, which succeed in balancing the water needs of humans and nature, strongly depend on our ability to manage trade-offs and offer an ecological approach to find a balance. Daily (2000) promotes the so-called Ecosystem Services Framework to systematically characterise ecosystem services at the local, regional, and global level integrating biophysical and social dimensions. Overall, the problem of trade-offs is well recognised and associated assessment and management challenges are already being addressed. Modern holistic environmental flow assessment methods should offer ways of evaluating trade-offs accounting for the fact that management choices play a vital role in determining the type and scope of spatial as well as temporal trade-offs (e.g. Rodríguez Jr. *et al.*, 2006). In this overall context participatory approaches play an increasingly important role. The current state of research on this is presented in the section 5.3.4 – 'Management tools for implementation of environmental flows'.

As was already pointed out in the interim report it is plausible to assume that water governance is a central determinant of trade-offs between ecosystem services (e.g. Brauman, 2007; Pahl-Wostl, 2009). Cumming, Cumming, and Redman (2006) found ecosystem services and governance are interlinked at various scales and that losses of ecosystem services are often caused by a mismatch of scales between ecosystem processes and governing institutions.

So far only little research is available that focuses on the linkages between water governance and ecosystem services, specifically analysing the role of governance regimes and how these influence trade-offs at different levels and the state of the aquatic environment. Water governance is understood here quite broadly as defined by the UNDP: "Water governance refers to the range of political, social, economic and administrative systems that are in place to regulate development and management of water resources and provisions of water services at different levels of society." (www.undp.org/water/about_us.html)

Brunckhorst (2002) emphasises how resource governance can mediate between the needs of society, the economy, and ecosystem services to achieve sustainability and a continuation of ecosystem functions and services. The importance of good governance for managing freshwater ecosystems is also highlighted by Postel (2003). She looks at the trade-offs between natural and human water needs and calls for a change in the mindset as the water needs of ecosystems have been neglected so far. Other studies linking governance and aquatic ecosystems tend to focus on marine ecosystems and fishery, which can be interpreted as a manifestation of their economic value. Ruckelshaus, Klinger, Knowlton, and DeMaster (2008), for instance, analyse marine ecosystem management and point out that governance structures play an important part in implementing ecosystem-based management. Further elaborations on the importance of governance are found in other articles on marine fishery. Hanna (1999) highlights how governance can contribute to sustainability in marine fishery and points out some functions that fishery governance must fulfil in order to achieve this goal. Juda and Hennesey (2001) focus on governance and the role it plays for the management concept of Large Marine Ecosystems (LMEs) which was emerging at the time. They point out how ecosystem productivity, fishery, and ecosystem health have received most attention when analysing LMEs whereas the socio-economic dimension and governance have often been neglected in comparison. Accordingly they highlight the governance framework within which ecosystem-based management takes place and propose to develop governance profiles that present and analyse existing frameworks and call for further studies that look at governance and ecosystem use.

5.3.3.2.3 Valuation as a Tool to Safeguard Ecosystem Service Functionality

Managing ecosystem services is closely associated with the valuation of these services, which is reflected in the Scopus literature. The search terms 'ecosystem service' and 'water' and 'management' generate a number of scientific articles addressing questions of valuation. Brauman *et al.* (2007) highlight the intrinsic value of ecosystem services because humans benefit from their use independent of a monetisation. However, as pointed out by Villa, Ceroni, and Krivov (2007) many of the studies focusing on valuation refer to monetised values which can then serve as incentives for conserving ecosystem services as in the case of Payments for Ecosystem Services (PAS) schemes (e.g. Jack, Kousky, & Sims, 2008).

Valuation is therefore an important supporting tool in decision-making especially with regard to water allocation. In this context Postel and Thompson Jr. (2005) draw attention to the fact that "natural ecosystem services lie outside the traditional domain of commercial markets" and are "undervalued and underprotected". Similarly Korsgaard, Jensen, Jønch-Clausen, Rosbjerg, and Schou (2008) address how environmental water needs are often disregarded and present an assessment approach which focuses on ecosystem services stressing the links between environmental flows and socio-economic values (see also section 5.3.4 – 'Management tools for implementation of environmental flows).

Altogether, there are many different approaches to valuation of ecosystem services and assessment frameworks. In a critical review Turner, Paavola, Cooper, Farber, Jessamy, and Georgiou (2003) analyse these and find that: i) aquatic ecosystems received least attention, ii) the majority of studies was limited to single function valuation, and iii) only few monitored changes over time. The importance of valuating ecosystem service across temporal and spatial scales is also highlighted by Hein, Van Koppen, De Groot, and Van Ierland (2006). Additional perspectives on ecosystem service valuation are introduced by Kumar and Kumar (2008) who focus on the psycho-cultural dimension and Bhagwat (2009) who examines the spiritual significance of ecosystems and their services. Apart from that, Meyerson *et al.* (2005) draw attention to the fact that perceptions of the importance of ecosystem services to society can vary, which must be addressed appropriately by decision-makers.

The importance of valuation as a tool for managing ecosystem services and trade-offs seems to be widely agreed upon and a multitude of approaches for valuation exist. Despite the clear advances of research on ecosystem service valuation Liu, Costanza, Farber, and Troy (2010) conclude that further syntheses of tools, skills and methodologies across the different disciplines are needed. As already pointed out in the interim report, the future challenge is to combine existing approaches to find ways of operationalising valuation consistently and reproducibly. Furthermore, Plummer (2009) draws attention to the fact that assigned values are site-specific and benefits are therefore difficult to transfer from one location to a similar one. One of the latest approaches to ecosystem valuation is the so-called 'sequential decision support system' (Turner, Morse-Jones, & Fisher, 2010; Morse-Jones, Turner, Fisher, & Luisetti, 2010) which takes these and other difficulties into consideration and is specifically aimed at practitioners.

5.3.3.2.4 Summary

The literature review underlines the importance of social-ecological linkages and human dependencies on aquatic ecosystem services. At the same time, it is evident that there are still significant research gaps, which need to be addressed in the future. In summary, the main gaps identified are related to our understanding of social-ecological linkages and trade-offs, as well as ecosystem service management including valuation and the role of governance.

For a better understanding of social-ecological linkages and trade-offs it is essential to improve the empirical database to be able to quantify environmental and human water needs, further analyse linkages within the ecological system, as well as relevant social factors and their interrelations that play a role in supporting human well-being. In this regard it is important to analyse multiple cause and effect relations in both directions between the social and ecological systems across temporal and spatial scales. Furthermore, methods to transfer results from one area to a comparable one without neglecting the context-specific particularities are needed.

Better understanding of the social-ecological linkages and the underlying dynamics and processes forms the fundamental basis for managing ecosystem services sustainably.

Additionally, the implementation of ecosystem service projects must be monitored and evaluated in order to be able to identify principles for best practice. Overall, there is a need for mainstreaming and operationalising approaches to managing ecosystem services including valuation. Finally, in order to arrive at sustainable solutions the role of governance must be analysed in more detail. This would also help to identify critical factors for adaptive capacity of social-ecological systems, which will be needed when facing the challenges of global change.

5.3.4 Application Area 4: Management Tools for Implementation of Environmental Flows (Focussing on Stakeholder Involvement)

5.3.4.1 Introduction

Environmental flow rules have to be determined using an approach based on best-available knowledge. Over 200 methods exist but standard methods are still lacking that allow for defensible and resource-effective assessment. The methods used for environmental flows assessment have developed from simple rule-of-thumb methods for the preservation of commercially important fish species to holistic methods that encompass ecologic as well as socio-economic aspects (Tharme, 2003). The Milestone Report of the BMBF-project (Pahl-Wostl, Kastens, & Van De Giesen, 2010) provides an overview of available methods and their history of development (see also: Tharme *et al.*, 2003; Dyson *et al.*, 2003).

Despite extensive development and testing of methodologies, examples for the successful implementation of environmental flow rules are rare (O'Keeffe & Le Quesne, 2009; Poff *et al.*, 2010). Experts in the BMBF project workshop held in February 2010 in Osnabrück concluded that the main obstacle for the environmental flow concept to have a real impact is related to the implementation of flow rules. The following topics have been determined to be the scientific and practical challenges in respect to flow implementation that are also reflected in the major findings from recent publications on environmental flows and international conferences in Australia (Garrick, Wigington, Aylward, & Hubert, 2008) and South Africa (Garrick *et al.*, 2009):

1. **Holistic assessment methodologies** are required to examine links and trade-offs between economic, environmental and sociological benefits of environmental flows (King, Brown, & Sabet, 2003; Korsgaard *et al.*, 2008).
2. The demand for predictive assessment of flow-ecology relationships requires long-term research activities and, thus, can stall implementation of flow rules. **Adaptive management approaches** for environmental flow assessment regard flow rules as flexible guiding principles that need to be adapted to new insights derived from experiments instead of definite standards (Poff *et al.*, 2003; Richter, Warner, Meyer, & Lutz, 2006; Garrick *et al.*, 2008, and Garrick *et al.*, 2009).
3. Implementation of flow rules depends upon the commitment of stakeholder groups towards measures or policies. Ecosystem services need to be valued by stakeholders including scientists, policy makers, water users and interest groups. Therefore, methods for **stakeholder involvement** in the valuation of ecosystem services as well as setting and implementation environmental flows are needed (O'Keefe & Le Quesne, 2009; Garrick *et al.*, 2008, and Garrick *et al.*, 2009).
4. **Water governance** reforms are needed to find effective institutional structures to assure implementation of environmental flows and preservation of ecosystem integrity (Garrick *et al.*, 2008, and Garrick *et al.*, 2009). Research on governance of environmental flows includes legislative (e.g. property rights), economic (e.g. water markets), and social aspects.

5.3.4.2 Recent Trends in Environmental Flow Research

The following section will review recent developments concerning all main impediments identified for the implementation of environmental flows. A special focus will be devoted to methods and frameworks that address participatory research on environmental flows.

5.3.4.2.1 Holistic Methods for Integrated Environmental Flow Assessment

An important methodological development is related to holistic environmental flow assessment methods that incorporate hydrological, hydraulic and habitat simulation models (Dyson *et al.*, 2003). The origin and application area of methods is quite diverse with the Instream Flow Incremental Methodology (IFIM) developed in the US (Bovee, 1986; Bovee *et al.*, 1998), the Holistic Method mostly applied in Australia (Arthington *et al.*, 1992; Arthington 1998), and the Catchment Abstraction Management Strategies (CAMS) from the UK Environment Agency (British Department of the Environment, Transport and the Regions [DETR] & Welsh Office, 1999). The DRIFT methodology (Downstream Response to Imposed Flow Transformation) originates from South Africa, and is the only method that includes societal consequences of flow alteration. It is based on the Building Block Method (BBM) (King & Louw, 1998; King, Tharme, & Watkins, 2000), and consists of four modules: a biophysical, socio-economic, scenario as well as economic module (King *et al.*, 2003). A common feature of holistic methodologies is the incorporation of knowledge from a range of disciplines through expert panels and/or the initiation of public participation processes (Dyson *et al.*, 2003). Scenario analysis allows for the assessment of consequences of flow alteration that can support decision-making on the desired state of a river and the related flow regime (King *et al.*, 2003). Koorsgard (2006) developed a Service Provision Index (SPI) that constitutes a modification of socio-economic module of the DRIFT methodology. The SPI links ecosystem services to flows, and thus allow for the valuation of environmental flows (Korsgaard, 2006; Korsgaard *et al.*, 2008).

5.3.4.2.2 Adaptive Management Approach

An adaptive management approach is promoted by various scholars as a meta-framework to allow for immediate management action under situations of incomplete knowledge on flow-ecology relationships, for instance due to knowledge gaps, limited resources or time-pressure (e.g. Richter *et al.*, 2006; O'Keeffe & Le Quesne, 2009).

Holling (1978) describes the adaptive management approach as "an integrated, multidisciplinary and systematic approach to improving management and accommodating change by learning from the outcomes of management policies and practices". Within an adaptive management approach, environmental flow rules are considered as hypotheses rather than ultimate truths. This understanding fosters learning about the water system through iterative improvement of environmental flow rules. Controlled experiments with environmental flows can provide valuable insights into the responses of riparian ecosystems (Poff *et al.*, 2003). Richter *et al.* (2006) developed a collaborative and adaptive management framework for setting environmental flow recommendations. Even though the application of data-intensive simulation models is explicitly considered to be important for the understanding of flow-ecology linkages, the framework applies exclusively conceptual qualitative models to highlight that adaptive management of environmental flows does not necessarily depend on quantitative modelling. The 5-step process comprises: (1) an orientation meeting in which scientific, political and other stakeholders meet to discuss the organisation of the overall process, and define sources of data relevant to the flow assessment; (2) preparation of a literature review and summary report that contains existing data and knowledge on the water system; (3) a flow recommendation workshop held by scientists from multiple disciplines to quantitatively define environmental flow rules based on collected information; (4) implementing the recommendation and monitoring of effects through a carefully designed monitoring programme including gauges and ecosystem indicators; and finally (5) initiation of data collection and research programmes that evaluate the outcomes of the implemented flow rules and gaps in knowledge and data. The steps 3-5 are continuously implemented to improve knowledge on the hydro-ecological system and refine environmental flows.

Acreman and King (2003) outlined a 10-step strategy for capacity building in Tanzania which contains also elements of general relevance (see Dyson et al. 2003). They propose an adaptive management approach through testing of flow assessment methods and implementation through a case study in a high-conflict area. In addition, cooperation between experts from different disciplines as well as international cooperation and field visits to learn from others' experiences are considered to be important. Further steps contain the instalment of a national database of knowledge on environmental flows, as well as a communication strategy to spread information to all relevant sectors and the public (Acreman & King, 2003).

Besides being an experimental approach, adaptive management strives towards the increase of adaptive capacity of human-environment systems (Baron et al., 2002; Pahl-Wostl, 2007a). Adaptive capacity can be defined as "the ability of a socio-ecological system to cope with novelty without losing options for the future" (Folke *et al.*, 2002). With respect to environmental flows, the Ecohydrology concept from UNESCO aims at the purposeful usage of ecosystem processes to fulfil water-related services for society. Water management can make use of ecosystem properties as natural infrastructure similar to engineering approaches to fulfil its goals (Zalewski, 2002). Through protection of ecosystem functions, the capacity of the ecosystem rises to absorb human impacts. For instance, wetlands can play an important role in denitrification processes originating from the application of fertilisers in agriculture (Zalewski, 2000). ‘Natural infrastructure’ is a similar concept that demands research on ecosystem functions and related services to allow water management to implement the most effective set of technical and conservation measures (Smith & Barchiesi, 2009).

In addition to enhance the adaptive capacity of ecosystems, adaptive management stresses collaborative management that includes multiple stakeholder groups. Social learning increases the adaptive capacity of stakeholder groups that can be defined as the ability to react to problems through informal learning processes and collective action (Pahl-Wostl *et al.*, 2007c). However, participatory approaches in environmental flow assessment are rare. Literature dealing with adaptive management approaches place more emphasis on the experimental component of adaptive management than on stakeholder involvement. The next section provides a review of participatory management tools for environmental flow assessment and implementation.

5.3.4.2.3 Participatory Management Tools

The environmental flow requirement in a river system is often a negotiated trade-off between multiple water users including the environment (Naiman *et al.*, 2002). Although the need for stakeholder involvement in this negotiation process has been highlighted quite often (e.g. Poff *et al.*, 2003; Rogers, 2006; O’Keeffe & Le Quesne, 2009; Smith, 2009), only a limited number of articles provide concrete approaches that specify the form and organisation of stakeholder involvement. Experiences with the implementation of the WFD have shown that stakeholder involvement needs to be well-planned to avoid frustration, for instance in case that real participation in decision-making is promised but only information or consultation realised (Acreman & Ferguson, 2010).

The research and implementation process of environmental flows provide different opportunities for participation, and can be divided into the following steps:

1. Definition of objectives for water management, and valuation of services provided by the water system
2. Analysis of ecosystem services – environmental flow relationships
3. Strategy development and implementation of environmental flows
4. Monitoring of effects of flow alteration, and strategy revision

An overview of participatory approaches concerning these steps of flow assessment and implementation is provided in the following sections.

5.3.4.2.4 Setting Objectives and Valuation of Ecosystem Services

To be accepted and effective, environmental assessments need to be incorporated in a basin-wide water management process. The definition of objectives for river management constitutes a social judgement that implies the valuation of services provided by the aquatic ecosystem. Thus, water management in general and environmental flow assessment in particular require the participation of multiple stakeholders comprising scientists, politicians, water users, and other affected groups (Poff *et al.*, 2003; Rogers, 2006; O’Keeffe & Le Quesne, 2009; Smith, 2009).

The overall objectives for water management are often predetermined by water legislations. In South Africa objectives are set according to ecological management targets (Rogers & Bestbier, 1997), and the EU WFD demands a good status of all water bodies (European

Community [EC], 2000). However, the transfer of these more general targets to specific and operational management goals permits the involvement of stakeholders.

The “objectives hierarchy” is a method that helps to connect aims and visions of non-specialist stakeholders with the often more technical knowledge of experts (O’Keeffe & Le Quesne, 2009). The process starts with the development of a vision statement that expresses the goal of river management by the stakeholder group. This often more general and unspecific vision is afterwards translated into a high-level objective that includes operational goals for water managers. Finally, sub-objectives and measureable indicators are determined to further specify management goals. A complementary approach is the "thresholds of potential concern” concept that sets upper and lower limits to operational indicators (Biggs & Rogers, 2003). In case of reaching a threshold level, a predetermined management response is applied comprising the analysis of causes, and the implementation of countermeasures.

Ecosystem functions and services that are provided by riverine ecosystems are manifold (see MEA, 2005). Economic methods for the monetary valuation of ecosystem services are widely applied. Forslund *et al.* (2009) provides an overview of methods and their potential and limitations to be used for environmental flow assessment. Despite various shortcomings of economic methods for valuation, they conclude that each method has the potential to raise awareness about roles and values of ecosystem services. The choice for ecosystem services and functions/processes to protect or restore requires the involvement of beneficiaries of services as well as individuals and organisations whose actions impair their provision (Chee, 2004). In addition to a clear vision about desired ecosystem services, Chee (2004) suggests an adaptive approach that includes learning about the problem and dynamics of the system resulting from the application of different measures. Risks and uncertainties involved have to be assessed, and a discussion about solutions and trade-offs between stakeholders facilitated. The combination of tools like discourse-based methods, simulation modelling, probabilistic risk assessment, multi-criteria analysis, and scenario planning are approaches that can facilitate participatory processes dealing with the valuation of ecosystem services (Chee, 2004). The DRIFT methodology (King *et al.*, 2003) fulfils most of these demands, especially in combination with the Service Provision Index (SPI) developed by Korsgaard (2006) (see section 2.1). The aim of the DRIFT methodology to predict future developments of human-technology-environment systems complies with the traditional command-and-control paradigm in water resources management. However, adaptive management approaches are more suitable to deal with inherent complexity of the system to be managed (Pahl-Wostl, 2007a). Thus, soft systems methods and group model building techniques could be suitable and innovative methodological approaches for environmental flow assessment.

5.3.4.2.5 Analyse Flow-Ecology Relationships

While the valuation of ecosystem services is a social process, the study of ecosystem functions that produce these services requires a scientific approach. Various scientific methods exist for the assessment of impacts of flow alteration on the ecosystem (see Dyson *et al.*, 2003; Tharme, 2003; Arthington *et al.*, 2006). Even though the analysis of flow-ecology relationships is more a scientific task, the specification of flow rules requires the assessment of risks and trade-offs that, in turn, makes the inclusion of the public in the decision-making process necessary. Participatory methods for the definition of environmental flow rules are rare. One example is the "flow-response graph" that helps to define acceptable and adverse resource impacts (Poff *et al.*, 2010).

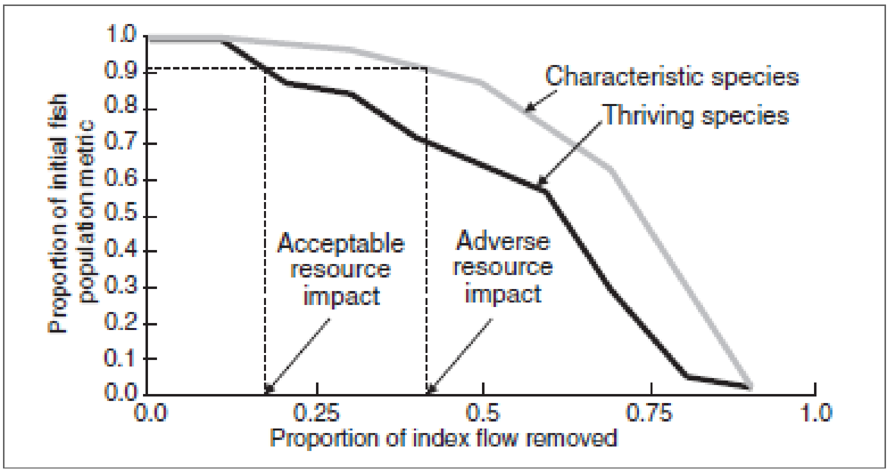

Figure 24: Progression from flow alteration–ecological response relationships to environmental flow standards (Poff *et al.*, 2010, modified from MGCAC, 2007).

Figure 24 illustrates the dependency of the fish population (differentiated between thriving and characteristic species) on allocated water for a stream type in Michigan, USA (MGCAC, 2007). A stakeholder committee decided that a 10% decline in the thriving population is an acceptable impact, while a 10% decline in the characteristic population is an adverse impact. Based on these definitions, environmental flow rules can be derived for operational management by selecting the corresponding flow alteration on the x-axis (Poff *et al.*, 2010).

5.3.4.2.6 Strategy Development and Implementation of Environmental Flows

The application of participatory methods is considered to increase commitment of stakeholders towards the implementation of flow rules rather than top-down decision-making. However, a concerted strategy of technical, economic, and political measures is necessary to achieve flow targets.

In modified river basins, the installed infrastructure can impede the implementation of environmental flows. For instance, the outlets of dams may restrict the maximum volume of flows (O'Keeffe & Le Quesne, 2009). New dam designs need to consider environmental flows as later re-operation are costly and sometimes even impossible. In addition to the technical design, structures like roads and houses as well as high-value agriculture can impede the implementation of high flows. Low flows can also be inhibited in case high flow volumes are required for the dilution of wastewater (Richter & Thomas, 2007).

Impoundments such as dams or weirs have been constructed for many purposes - like water supply, hydropower generation, or flood control – while the assurance of environmental flows was rarely considered (Dyson *et al.*, 2003; Acreman *et al.*, 2009). Thus, dams usually involve major changes in the natural flow regimes up to total elimination of the natural variability. This caused a widespread impairment of riverine ecosystems and ecosystem services provided (World Commission on Dams [WCD], 2000; MEA, 2005). In the UK and similarly in France and Brasil, most of the dams (about 70%) constantly release about 16% of the mean flow throughout the year. Only a few dams realise variations of the flow release, while other impoundments regularly do not release any volumes at all (Acreman *et al.*, 2009). Richter and Thomas (2007) provide a framework for the assessment of potential benefits that can be restored through dam re-operation. Effective strategies for dam re-operation also have to include the distribution and usage of benefits from dam operation as well as socio-political and economic drivers. They suggest the inclusion of stakeholders in the setting of specific and short-term goals for water management as well as dam re-operation. However, dam re-operation is not possible in all cases as environmental flows are just one aspect of dam regulations, and redesign can reduce profitability of other services (Dyson *et al.*, 2003).

Other limiting factors for flow implementation belong to legislative, economic, or social aspects. Holistic methods allow for an interdisciplinary analysis of consequences caused by flow allocation rules (see section 2.1). In particular the sociological dimension as well as governance of environmental flows requires further research. While the aspects of the former is already included in the DRIFT methodology (King *et al.*, 2003), governance of environmental flows mainly deals with economic aspects and instruments. Further details on the governance of environmental flows are given in section 2.4.

5.3.4.2.7 Monitoring and Revision

Monitoring is an integral step of adaptive management to learn from past actions and thereby iteratively improve measures. An effective monitoring network should reveal unintended and unforeseen trends and thus induce a rethinking and reassessment of implementation strategies and underlying assumptions.

Monitoring of environmental flows has two purposes. First, to control the implementation of flows at several points of a river. Second to monitor the achievement of a desired condition, for instance, in respect to ecology, or geomorphology (King & Brown, 2006). To assure the effective learning from implementation, suitable hypotheses and indicators for monitoring has to be predefined. As described above in section 2.3.1, the objectives hierarchy and Threshold of Potential Concern (TPC) are methods to find and evaluate operable indicators that are linked to overall management goals (Rogers & Biggs, 1999).

Another important task besides the implementation of measures is the definition of knowledge gaps that require further research. The participatory process as well as monitoring can reveal case-specific and practical research needs that guide the work of the scientific community (Acreman & King, 2003; Richter *et al.*, 2006).

5.3.4.2.8 Water Governance

Similar to the topic of environmental flows, simplistic as well as detailed approaches for the analysis of governance regime have been developed. While institutional panaceas devised by simplistic approaches turned out to be not useful or even detrimental (Ostrom, 2007; Ingram, 2008), detailed analyses are too resource intensive to be applied on a case-by-case basis, and make generalisations difficult. Thus, a diagnostic and systemic approach of intermediate complexity is more promising for the analysis of resource governance systems to allow for transfer of findings across cases (Pahl-Wostl, 1995; Ostrom, 2007; Young, 2007). Applications of this approach have been realised for resource governance (Ostrom, 2007; Young, 2008) as well as more specifically for water governance regimes (Pahl-Wostl, 2009).

Research on governance of environmental flows from a more general, rather than context-sensitive, perspective is lacking. Legislative requirements for the consideration and implementation of environmental flows are diverse around the globe. Research on the implementation of environmental flows in legislation already exists but is restricted to specific pieces of legislation like the EU Water Framework Directive (Acreman *et al.*, 2009; Acreman & Ferguson, 2010). Water markets are an often promoted solution to achieve efficient water allocation and redistribution of water. Different forms of water markets exist that are open markets, spot markets, administrative water trading, and informal water markets (Le Quesne, Quesne, Pegram, & von der Heyden, 2007). Australia has often been referred to as an example for the network mode of governance even though market and hierarchical elements are important aspects in Australian water governance as well (Bell & Park, 2006; Bell & Quiggin, 2008). Due to the interplay of all governance modes, research on governance of environmental flows is needed to detect general attributes of effective governance regimes and learn from the comparative analysis.

5.3.4.2.9 Summary

This application area report focuses on management tools for the implementation of environmental flows. Scientific knowledge on environmental flows for individual cases has been determined to be quite developed while the implementation runs far behind (O'Keeffe & Le Quesne, 2009). Nevertheless, gaps in scientific knowledge exist. There is a lack of knowledge about the fresh water status, quantitative knowledge about flow-ecology links, as well as quantitative knowledge on the importance of freshwater ecosystem services for human livelihood.

Furthermore, substantial research is still needed in relation to the implementation of environmental flows in water management. More generic and large scale methods are needed to cope with the increasing pressure on freshwater ecosystems. In this respect, the ELOHA-framework from Poff *et al.* (2010) is an innovative approach by developing river typologies that can be applied for regional or national flow assessment. To assess social, economic and environmental consequences of flow alteration, and allow for the balancing of trade-offs it is important to develop holistic methods like the DRIFT methodology (King *et al.*, 2003). This represents an integrative approach which however requires further development, for instance in respect to the consideration of a broader set of social aspects. To ensure timely implementation of environmental flows and deal constructively with incomplete knowledge and data about flow-ecology linkages adaptive management approaches are required. Some frameworks for adaptive management processes have already been developed but these need to be linked to general water resource management processes and concepts like integrated and adaptive water resources management to set environmental flows higher on the water management agenda.

Additionally, further research and testing of participatory methods and tools will be required to assess consequences of flow alteration and related ecosystem services and risks. Participatory approaches help to increase commitment to flow rules, develop holistic strategies to coordinate measures and engagement of actors, and allow for social judgement on ecosystem services. With regard to the design and operation of technical infrastructure innovative approaches must be developed that consider flow rules to overcome impediments to the implementation of environmental flows in case of modified rivers and related wetlands. Again integrative strategic approaches are needed that combine these technical aspects with economic and social measures.

Finally, water governance is another aspect that requires further research. Several institutional barriers to flow reallocation were identified, such as unclear property rights, high political and economic costs, weak institutional capacity, and existing water management legislation. The analysis of barriers to and drivers of environmental flow implementation in governance regimes is thus an important research topic.

5.4 Synthesis: Future Research Needs and Recommendations for Future Research Programmes

Based on the results of the literature reviews future research needs are assessed in relation to knowledge gaps, science-policy interplay, the relevance of the problem, and the suitability to be implemented in the German scientific community.

5.4.1 Gaps in Scientific Knowledge and Potential to Achieve Scientific Breakthrough

The literature reviews underline the relevance of each of the four Application Areas on its own but already have revealed some significant research gaps which were summarised at the end of each section of an Application Area.

While each Application Area has its own priorities and varying future research needs, it becomes apparent that the different areas are closely intertwined and cannot be looked at separately. In all four Application Areas the need for improving the knowledge base in relation to various ecological processes is highlighted. It has become apparent that the understanding of these highly complex processes forms an important basis for developing appropriate management approaches and plays a vital role not only in better understanding the functional linkages of natural and technical aquatic ecosystems but also the social-ecological linkages. This forms an important basis for developing appropriate management approaches. For the latter, the role of governance regimes must also be explored further in order to arrive at sustainable management solutions balancing human and natural water demands.

Furthermore, it was pointed out across the Application Areas that research must expand beyond individual system compartments or simple cause and effect relations to better grasp the complexity of the dynamics in the natural, as well as the social and technical systems across spatial and temporal scales. Monitoring is an important aspect in this context. As the empirical data collected are very site- and context specific methods of transferring results to other regions or scales must be developed.

The research gaps detected in the Application Area reports show the interdisciplinary character of this Theme Cluster. Detailed knowledge is required from the natural, engineering and social sciences for the purposeful manipulation of flow and water bodies to restore, maintain and expand ecosystem services. In this respect, the ‘Environmental Flow’ concept is a suitable approach to link hydrological characteristics of river flows to riverine ecosystem and services they provide. This concept is also applied to the design and management of technical infrastructure like dams and weirs to mimic the flow regime of rivers. Thus, ‘environmental flows’ is an approach that allows the integration of disciplinary knowledge and topics that have been stated in this Theme Cluster.

A quantitative literature research has been conducted for each Application Area using the Scopus citation database of research literature and quality web sources. The analysis explores the development of publications and specific trends in every Application Area for the past 10 years. The results comprise the search terms and number of hits in the title, abstract or keywords in the category “articles and reviews”. Selected findings are presented below.

The human dimension has gained in importance in recent years but the Scopus analyses show that engineering and natural science publications clearly dominate all four Application Areas. An integration of the social science is called for by various authors and emphasis is put on interdisciplinary approaches rather than additional disciplinary research. Further integration is also needed in relation to research approaches within and between the different Application Areas to arrive at a common conceptual basis on which future research can be based.

The number of publications on ‘environmental flows’ increased by nearly five times in the last 10 years, demonstrating the growing importance of environmental flow research (see Table 9). The sub-themes participatory and adaptive management, and flow implementation show an increasing tendency, too. The number of publications for the term ‘environmental flow’ quadrupled, while participatory approaches increased from zero in 1999 to 10 publications in 2009 (see Table 9). Publications on management or implementation of environmental flows have even increased by a factor 40. The links of ecosystem services and governance to environmental flows have been of minor relevance in scientific publications during this time frame despite the special importance of these topics (cf. section 5.3.3 and 5.3.4).

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
EF	16	17	24	17	40	22	45	47	43	71	68	31
EF AND PART OR STAK OR COM	0	2	1	2	8	4	4	5	4	10	10	8
EF AND ADAP OR ADAPT	1	0	0	3	3	0	1	2	2	2	2	7
EF AND IMPL OR MANAG	1	3	8	9	20	11	20	22	13	34	40	19
EF AND ECO	0	0	0	0	0	0	0	0	0	2	0	2
EF AND GOV	0	0	0	0	0	0	3	0	0	0	1	0

Relate to base year = Base year Factor; Base year = 1999.

Number of publications (choice for search space “article” or “review”) with “search term” in title, abstract or key words.

Abbreviations:
EF = “Environmental Flow”, PAR = participation, STAK = stakeholder, COM = communities, ADAP = adaptive, ADAPT = adaptation, IMPL = implementation, MANAG = management, ECO = “ecosystem service”, GOV = governance.

Table 9: Quantitative Scopus analysis (1999-2010).

The high relevance of environmental flows in research and practice is reflected in the programme of major scientific and political conferences on water. At the World Water Week 2009 in Stockholm, two seminars and one workshop were explicitly related to environmental flows implementation as well as the linkage to sustainable development, poverty alleviation, biodiversity conservation, and integrated water resources management. ‘Environmental flows’ also has been a prominent topic at the World Water Forum 2009 in Istanbul. It was raised in two out of six thematic areas as well as the political process. Integrated approaches for flow assessment have been discussed at the World Water Forum including stakeholder participation in the investigation, valuation and management of multiple use and functions of water services. Other important topics have been flow indicators, and environmental flows as a central measure to balance human and ecological needs.

Due to the high political and scientific relevance of environmental flows, large international programmes on environmental flow assessment and implementation exist. Research initiatives are conducted by the International Union for Conservation of Nature (IUCN), the International Water management Institute (IWMI), and the International Hydrological Programme (IHP) of the UNESCO. On the national level, the Swedish Environmental Flows Initiative reflects the importance of the concept for national water practice and research (Forslund *et al.*, 2009).

As highlighted at the World Water Forum 2009, an interdisciplinary approach is needed to study the interplay between terrestrial ecosystems, landscapes and the water cycle, as well as operationalisation of the findings of this research for policy and management on national and local scales. Research on environmental flows is needed that combines knowledge from the natural sciences with those from social and technical disciplines. This will improve the ability of holistic assessment of flow rules and detection of integrated strategies for implementation in an IWRM framework.

Altogether, the challenges placed upon future research are considerable, but surmountable with good potential to address the gaps successfully building upon existing research. Especially, the concept of “Environmental flows” is suitable to embrace all the distinct research fields stated in the Application Areas. Thus, a future research programme should include this integrative concept that is also highly relevant for prevailing social and political issues.

5.4.2 Science-Policy Interplay

The overall theme of manipulating flow and water bodies for managing ecosystem services with its four major Application Areas is of high relevance to multiple stakeholder groups at all levels. These include governmental agencies and water managers that are in charge of water resource management or environmental protection. Water user groups have a similar interest in the topic as the allocation of water for environmental flows can have effects on the water availability for other uses. For instance, environmental flows can have a limiting effect on economic activities (e.g. reduced quantities for irrigation in agricultural sector) as well as supportive effects (e.g. habitat for commercial fish). The general public needs to be included in the valuation of ecosystem services and the evaluation of risks that come along with deviations from the natural flow regime of the river.

Since water plays a key role in the landscape system (Falkenmark & Mikulski, 1994), the management of environmental flows must be an integral aspect of river basin management and landscape planning. Impacts of global change, like increased exposure to floods and droughts, are predominantly linked to the water system (Lehner, Döll, Alcamo, Henrichs, & Kaspar, 2006; Smith & Barchiesi, 2009). Thus, the concept of environmental flows can support the management of complex landscape ecosystems by providing a key variable that influences ecologic processes at large scales. In this respect, Dyson *et al.* (2003) suggest the recognition and usage of environmental flows as a water resources management tool. Regional environmental flow standards could be developed and integrated into the implementation of the EU Water Framework Directive. Even though environmental flows are not stated explicitly in the directive, it is generally accepted that the hydrological regime is central to achieving a good status for all water bodies (Acreman & Ferguson, 2010). The Water Framework Directive constitutes an innovative piece of water legislation, and thus, provides a unique context to apply research on environmental flows combined with empirical analysis and participatory processes in European river basins. In addition to river conservation, river restoration processes, for instance for heavily modified water bodies, need to consider environmental flows to be effective. The concept of environmental flows particularly facilitates the design and implementation of concerted technological, social and economic measures for the achievement of a good ecological status. In general, the assessment and implementation of environmental flows are urgent tasks for various freshwater ecosystems around the world. Straightening of river beds and construction of impoundments have been realised in many river basins around the globe. This caused degradation of riverine ecosystems and related ecosystem services (WCD, 2000).

At the international level, the significance of ecosystem services has already been recognised, which is reflected in the establishment of the UNEP ad hoc intergovernmental and multi-stakeholder group which addresses the intergovernmental science-policy interface on biodiversity and ecosystem services. The group has already met twice in 2008 and 2009 - the last meeting will take place in June 2010 - and agreed on the aims to find ways of improving the science-policy interface for biodiversity and ecosystem services across all spatial scales to form a basis for achieving human well-being and sustainable development:

> *“There is growing consensus that strengthening the interrelations between science and policy at all levels is necessary (but not sufficient) for more effective governance of biodiversity and ecosystem services. Current environmental problems, often of considerable magnitude and complexity, challenge science, politics, policy and their interrelations in unprecedented ways, confronting them with situations in which facts are uncertain, values in dispute, stakes high and decisions urgent.”* (UNEP/IPBES/2/2 published 2009)

Ways to cooperate and share knowledge and experiences must be developed at all levels. Short and simplified communication channels enabling direct informal exchange without the constraints of formal institutional structures could offer progress in relation to this. For future research programmes it may be advisable to make the policy-science interface an integral part of projects where needed and foster cooperation and exchange throughout the duration of the research programme making it a learning experience for all involved.

5.4.3 Relevance of International Policy

Ecological, morphological and biological degradation of rivers are major problems of increasing severity. Climate change is likely to lead to thermal and hydrological changes that aggravate the situation in many of the world’s river basins (Malmqvist & Rundle, 2002) while instantaneously global water demand for society and economy is expected to increase (UNEP, 2007).

Specifically urban water systems are characterised by severe changes of natural conditions and fluxes of water, by large-scale technical systems of water capture, treatment, storage and distribution as well as waste and runoff collection, purification and discharge to the receiving water bodies. Surface and ground water are usually heavily modified in quality and function. Downstream water users and the aquatic environment are suffering severely from the impact of urban water systems, especially in semi-arid and arid regions. In view of expected trends in demography (decreasing and aging population) in Germany and of climate change and its consequences on the hydrological regime, the urban water systems appear quite vulnerable and need preventive research and adapted management actions. However, our knowledge of the fundamental processes in urban water is still limited and not sufficient to predict the consequences of different scenarios for cities with various conditions.

The need to find innovative ways to satisfy human demands and protect the functioning of ecosystems and related services at the same time is evident. Forslund *et al.* (2009) highlight the important role of environmental flows in climate adaptation strategies. As a reaction to these problems, many water legislations around the world demand protection and improvement of riverine ecosystems, and a key role of stakeholder involvement in this process. In most of the cases, environmental flows are not stated explicitly in the national water legislations. Examples for the specification of approaches for the management of environmental flows are the definition of minimum flows in the Swiss Water Protection Act, regulated management for the provision of environmental benefits in the Australian Murray Darling Basin, and statutory management plans that demand a requirement for environmental flows in the South Australian Water Resources Act. The South African Water Act applies a combination of the techniques mentioned above to allocate water for ecosystems (Dyson *et al.*, 2003). From a social perspective, environmental flows are important policy instruments for poverty alleviation (e.g. King *et al.*, 2003) and achievement of the Millennium Development Goals (Forslund *et al.*, 2009).

Focusing on ecosystem services Carpenter *et al.* (2009) point out how some existing policies and practices aimed at achieving win-win situations benefiting both humans and nature, lack a sound knowledge base and are instead based on untested assumptions. Consequently, Carpenter *et al.* (2009) emphasise that it is “imperative for the policy and science communities [to] establish a capacity to create and implement policies for social-ecological systems, predict consequences, and evaluate outcomes”. Furthermore it must be borne in mind that different policies and actions are needed at different levels (Zehnder, 2010).

Science must assist policy-makers in identifying what kind of policies and tasks are required at the regional, national or international level. Scientific findings must be operationalised and communicated appropriately. For policy-makers it is important to acknowledge human dependence on intact ecosystem services and explicitly integrate environmental water needs into their policies, especially where the flow regimes vary and where the water needs are linked to water quantity and quality (Baron *et al.*, 2002). As the ecological and social system are deeply intertwined, understanding the underlying processes and dynamics, also in relation to the hydro-ecological linkages, is crucial for policy makers to be able to make informed decisions.

5.4.4 Suitability of the Programme to be Implemented in the German Scientific Community

Following the results from this Theme Cluster, the development and integration of knowledge from environmental engineering, hydrology, water governance, and participatory and adaptive water management through research on “environmental flows” is considered to be important to find effective and sustainable approaches for water management. In this section, the suitability of research on environmental flows for the German research community is analysed.

When it comes to the application of environmental flow methodologies, the USA runs far ahead of other countries. Tharme (2003) counted the application of 77 methodologies in the USA that reflects the high priority and long history of environmental flow assessments.

Australia (37), the UK (23), Canada (22), South Africa (20), and New Zealand (20) are in a leading position as well (Tharme, 2003). However, all reported cases in Europe add up to 122, demonstrating the importance and relevance of environmental flow methodologies in Europe. Germany with 8 published applications resides in the European average (own calculations based on Tharme, 2003).

An analysis of scientific publications has been conducted on research fields that were determined to be most important for the implementation of environmental flows. In this analysis, the nationality of authors' affiliations of detected publications was determined from the ISI Web-of-Science database to examine the strengths of national research communities in the research fields of hydrological sciences, water governance, participatory water management, adaptive water management, and environmental flows. Table 10 shows the results that demonstrate an excellent position in the top-5 for Germany in the field of water governance, participatory approaches and adaptive water management, and also a leading position in hydrological sciences (rank 6). With eight scientific publications, Germany resides in the top-10 of environmental flow research. The gap towards the leading nation Australia is considerable though (124 publications).

Topic		Hydrological Sciences	Water Governance	Participatory water Management	Adaptive Water Management	Environmental Flows
Search Term(s)		hydrology	water AND governance	water management ANDparticipation	water management AND (adaptive OR adaptation)	"environmental flows"
Rank	1	USA (5,888)	USA (157)	USA (206)	USA (379)	AUSTRALIA (124)
	2	CANADA (1,188)	ENGLAND (93)	ENGLAND (69)	AUSTRALIA (111)	USA (69)
	3	ENGLAND (1,103)	AUSTRALIA (48)	AUSTRALIA (57)	CANADA (93)	ENGLAND (23)
	4	FRANCE (835)	**GERMANY (35)**	**GERMANY (53)**	ENGLAND (84)	PEOPLES R CHINA (21)
	5	AUSTRALIA (766)	NETHERLANDS (35)	NETHERLANDS (50)	**GERMANY (80)**	SOUTH AFRICA (15)
	6	**GERMANY (658)**	CANADA (34)	SOUTH AFRICA (40)	NETHERLANDS (65)	CANADA (14)
	7	NETHERLANDS (530)	SOUTH AFRICA (26)	CANADA (38)	FRANCE (44)	NETHERLANDS (10)
	8	PEOPLES R CHINA (389)	FRANCE (21)	INDIA (35)	SPAIN (43)	**GERMANY (8)**
	9	ITALY (356)	PEOPLES R CHINA (18)	FRANCE (27)	SOUTH AFRICA (36)	FRANCE (7)
	10	SWITZERLAND (287)	SPAIN (18)	PEOPLES R CHINA (26)	PEOPLES R CHINA (34)	JAPAN (7)

Table 10: Number of publications on selected search terms in the ISI Web-of-Science database, ranked by the nationality of authors' affiliations.

These results show the high potential for the German research community to take a leading position in the field of environmental flows. In particular, collaborations between scientists from water governance, as well as participatory and adaptive water management with the environmental flow research community are promising to secure and strengthen Germany's leading position, and develop innovative approaches for the assessment and implementation of environmental flows.

5.4.5 Recommendations for Future Research Programmes

The overarching 'Environmental Flow' concept provides a suitable framework for a future research programme. It has the capacity to integrate the key topics dealt with in the individual Application Areas into a holistic approach. Particular attention should be paid to improving links to the human dimension with a focus on governance research, as well as existing management approaches in particular IWRM and the concept of Adaptive Management.

It is suggested to install integrative and complimentary projects with an overarching synthesis project to contribute to advancing Environmental Flows research with all its facets. This should link into existing efforts, e.g. as laid out in section 5.4.1, to contribute to developing common conceptual and methodological approaches. New and international unique collaboration of leading organisations is necessary to open new possibilities and horizons for future progress in fundamental research and innovations.

Preferably such an international research programme would run over several years in order to capture not only spatial but also temporal variability in flow, the driving variable. However, also a sequence of projects building up on each other may be a feasible approach to advance research. This would add valuable knowledge in obtaining a better understanding of freshwater ecosystems, including groundwater, environmental flows, and the associated challenges pointed out in this report. More specifically at a European level and in Germany environmental flows research should also aim at contributing to the implementation of the Water Framework Directive.

Figure 25 depicts a possible structure for a future research programme of the BMBF.

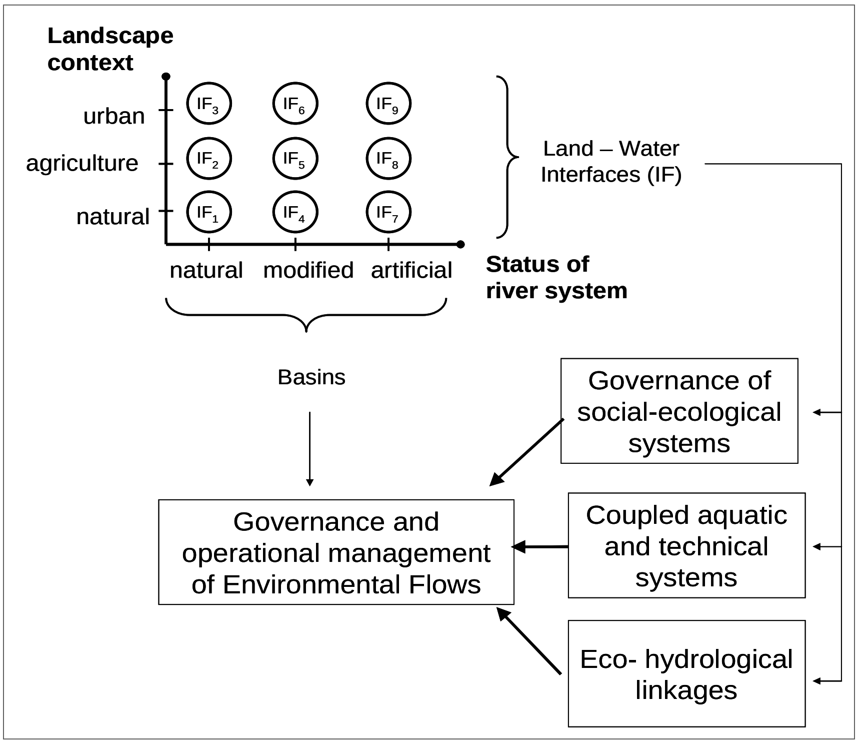

Figure 25: Suggested project structure for a future BMBF research programme that bases on the finding of the Theme Cluster.

The topics “Governance of socio-ecological systems”, “Coupled aquatic and technical systems”, and “Eco- hydrological Linkages” presented in Figure 25 have been identified to be key challenges of the first three application areas (sections 5.3.1 – 5.3.3). Findings relating to these key topics are then combined under the overall framework of environmental flow research with a special focus on governance and operational management.

The status of river systems can be heterogeneous in respect to their level of modification (i.e. geomorphologic, technical infrastructure), and is closely linked to the adjacent landscape context (cf. section 5.3.1). Thus, research projects focusing on these topics need to consider different land-water interfaces pertaining to the gradients of “status of river system” and the “landscape context”. A suggestion is to develop several case studies at the sub-basin level to produce empirical data called for within in all the aforementioned application areas and develop a common conceptual and methodological research framework by combining the various attributes, as depicted in Figure 25.

Such an integrative approach with a synthesis project allows for the integration of empirical data and theoretical concepts, and provides a basis for identifying opportunities to effectively implement the findings in river-basin management and governance. Thus, the case study level for the integrative approach as a whole should be the entire river basin in order to develop and test approaches for the integrated governance of basins with heterogeneous attributes in respect to the river system and the landscape context.

6 Concluding Comments

The report comprises recommendations for four research programmes based on the four thematic clusters identified as important future research areas. No attempt is made to rank these four thematic clusters since each addresses an important research field. Furthermore, it is entirely unclear how much money will be available for the implementation of a future research programme.

However, the following general recommendations are made for the implementation of a future research programme:

- Research should be interdisciplinary and integrate in particular the social and the natural sciences. Here is an urgent need for innovation from both the scientific and the policy perspective with a high potential to achieve large international visibility.
- Any programme should also include a community building component in particular in the field of water governance. Again, one can identify here an urgent need from both the scientific and the policy perspective with a high potential to achieve large international visibility.
- A modular structure is preferrable to very large integrated projects like in the GLOWA programme or the IPs of the 6th Framework Programme of the EU. The latter result in a large overhead in coordination and tend to be less innovative than smaller units. However, in order to avoid fragmentation a larger number of smaller projects should be linked by a joint integration platform and project. To ensure that synergies can be exploited and conclusions can be drawn from a larger knowledge base the integration project should be stronger than in a typical SPP of the DFG and comprise, for example, the development of a shared conceptual framework and knowledge base.
- To increase the policy impact of a new programme interministerial collaboration, in particular with the BMU, is recommended.

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8 Appendices

All appendices to the four theme clusters can be found on CD enclosed to this report. The following list of documents is the table of contents for the documents on CD, which is also contained in the CD.

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Expertise to the thematic cluster document: Water related risks, vulnerability(ies) and adaptive capacities under conditions of uncertainty

Author: Janos Bogardi

The respective report identifying research priorities and suggesting draft research project outlines was prepared by Mr Niklas Gebert, PD Dr.-Ing, Jörn Birkmann United Nations University Institute for Environment and Human Security (UNU-EHS) and Dr. Christian Kuhlicke Helmholtz Umwelt Forschungszentrum (UFZ). The report is based on the recommendations of an expert workshop held in February 2010 in Osnabrück. The corresponding working group in the workshop identified 3 priority application (challenge) areas:

1. Risk governance and institutional vulnerability
2. Risk and adaption related to urban dynamics
3. Vulnerability of coupled critical (supply) infrastructures/systems

All three areas are very relevant as they highlight emerging new concern areas of high relevance for human security.

Area 1 is reflecting the recent recognition that even if the disaster response capacities were available, without proper framework for the different actors (governance at different levels) risk alleviation and management could fail. Beyond the urgent need for sound risk governance frameworks (reflecting various segments of the disaster cycle) the (internal) vulnerability of formal and informal institutions could be a reason for unabated risk and could even prove fatal, once a vulnerable agency (command line or even a social habit) fails to perform its duties in an emergency or rescue operation. The fact that lack of risk governance and institutional vulnerability are not exclusive attributes of less developed countries was tragically demonstrated in 2005 during the onslaught of Hurricane Katrina on New Orleans. In a different (technical disaster) context the Gulf of Mexico is again a sad example of the consequences of lack of risk governance and the evidence of institutional vulnerability to prevent, to mitigate or to solve environmental emergencies like the oil spill which is still active for more than a month after the collapse of a drilling platform.

The need to act will be accentuated through the expected deterioration of the hazard through the ongoing climate change, though vulnerabilities may deteriorate faster and partially independent of climate change. Adaptations both to extreme events and to climate change are needed. They may be the same or similar steps/processes but his potential coincidence does not imply that adaptation to climate change and to water related extreme events would be the same. Social, economic and political changes are swifter and occur on a shorter time scale than climate change. Adaptation to extreme events like floods, droughts, storms etc. are principally improved preparedness, while adaption to climate change will certainly include large scale land change and potentially migration with inherent, potentially decades long time scales.

It is very much welcomed that the need to address risk governance and institutional vulnerability has been identified. It can be expected that proper risk governance would mitigate institutional vulnerability. As a corollary institutional vulnerability, its roots and patterns should be well analyzed in order to identify the weak points in institutional response capacities and performance. These ‘neuralgic’ points are then to be addressed by improved risk governance and subsequent risk management. Hence the two elements better risk governance and less institutional vulnerability are closely interrelated and should therefore be tackled either one project or be conceived as a sequence of linked research projects.

Area 2 is an interesting focus on urban dynamics and its impact on risks and adaptation. While in policy papers the trend towards urban growth worldwide is highlighted the present research area analysis paper shows a much more complex picture. Urban growth is associated by both economic success and attraction, but it is also fueled by rural poverty and deteriorating livelihoods in the hinterland. The phenomenal and unregulated growth of urban agglomerations takes place mainly in developing countries. Urban planning, infrastructure and governance are simply overwhelming. As the number of inhabitants in so called informal urban settlements is around one billion people as of 2010 the global scale of the problem becomes evident.

However the global urban dynamics has another face too. Due to economic transformation towards service societies, aging and drastically changed reproduction patterns there are hitherto major urban centers (both megacities but also lesser urban agglomerations), especially in the developed (Northern) countries which actually shrink. As the population of associated rural areas declines even faster the potential pool of people to draw upon is also quickly exhausted. Several studies revealed already that shifting age distribution and negative growth of total population increased urban vulnerability and decreased the capacities (incl. financial ones) of those municipalities affected by these phenomena.

No doubt that both dimensions of urban dynamics: rapid growth and precipitous decline have negative impact on risks (sharply increasing trend). Malfunctioning social and infrastructure services and adaptation capacities can be found both in swift hazard as well as creeping deterioration (like climate change) contexts.

The above described double facet of urban dynamics and its alarming, yet different types of consequences imply that research related to Area 2 should be carried out at different urban scales and settings both in developing and developed countries. Further it is highly recommended to select urban agglomerations as case study areas located close to water courses, in deltas, along the coasts and in mountainous areas. The German research community is very well prepared to get engaged in high level, multidisciplinary research in the above outlined research areas.

Area 3 is the logical consequence of the two previously identified research foci. Parallel to the institutional vulnerability the more physically oriented vulnerability of (critical) infrastructure systems (CIS) should also be seen as a priority research area. Dependence on electricity, telecommunication, transport, water supply, sanitation, heat supply etc have created their own vulnerabilities. Crucial infrastructure elements may break down or being destroyed during extreme events (floods, storms etc) and suddenly expose, through its dependence, the vulnerability of the whole society, including even those who are physically not exposed to the relevant hazard event. Thus the social-ecological dimensions of vulnerability are also relevant and should be assessed. Critical infrastructure lines, once knocked out facilitate the propagation of hazard impacts from far away events.

No doubt that critical infrastructure will be (or already being) affected by the consequences of climate change. Increased frequency of heat waves for example raise the temperature of water bodies, thus rendering affected rivers unfit to provide water for cooling purposes. Electricity cuts may result. Due to its primordial importance research studies dealing with infrastructure risk (hazards, exposure and vulnerability) and reliability will gain in importance. Adaptation, both in sense of disaster preparedness (more flexible interlinked systems with reserve capacities) and in the context of climate change (more robust and potentially modified systems) will have to be considered.

I. Results of experts interviews

Altogether 12 experts filled in the questionnaire. In the following the interview results are summarized and ranked according to the number of times mentioned.

1. What are the most important future research questions and gaps in the field of water research including global change?	
Nr.	**Themes**
1.	**Water Management** • Practical cooperation and development cooperation • Develop themes in an international pan-European context • Decision-support-systems • Instruments (systematic processing of information) • Water use efficiency • Economic valuation of water resources (Water pricing) • Integrative water resource management
2.	**Governance questions** • Water governance • International cooperation • Embed adaptive strategies into governance structures • Development cooperation • Governance instruments • Processes of change (global & regional)
3.	**Data & Models** • Uncertainties • Future scenarios • Improvement of data management & evaluation methods
4.	**Water quality and quantity** • Anthropogenic toxics (fertiliser, drugs, etc.) • Ecosystem services • Sustainability und water protection • Management of green water resources (including the 3 conventions of climate, desertification und biodiversity) • Transboundary water transfers
5.	**Water shortage** • Water supply • Water treatment • Water re-use option • Water-use efficiency (sustainable land-use)

2. Could the scientific community of water researchers deal with these future

research questions and gaps?
Most of the experts (75%) gave a negative answer to this question. The remaining 25% gave a positive answer.
reasons for a negative answer
• Research fragmentation (too many disciplines in too many locations) • No research headquarters/research centres (The international and national political perception is affected by such centres) • German water research needs a greater international focus • Need for more integrative and interdisciplinary projects with connections between these research projects • Conflicts between the expectations of knowledge users and knowledge producers/ researchers • More cooperation between universities and companies are needed • Development cooperation: BMBF-Projects are badly adapted to actual demands (Outputs are often not adapted to the requirement in specific regions)
reasons for a positive answer
• German researchers are of international standing in hydrology, water chemistry, climate change research • Data management and monitoring • Communication of research results • Implication of planning

3. In which research areas do we lack expertise and support?	
Nr.	**Themes**
1.	**Support interface between research and practise** • Development cooperation • Research support instruments (need for compatible instruments) • Integrative research (inter- and transdisciplinary research) • further research interests and needs must be well-timed
2.	**Basic Research** • Long term support of research • Data basis of long term monitoring • Specific knowledge of the research areas (especially social science data)
3.	**Virtual Water (**Expertise for blue and green water)
4.	**Ecosystem services**

4. How to deal with future research programs (currently politically relevant)

Nr.	Themes
	Professional management • For project leaders to ensure inter- and transdisciplinary research • Professional structure • Enhancement of management for greater added value • Adaptation to local structures (Administration, etc.) • Innovative research questions • Relevance to practice • Long term perspective • Main research focus • Including basic research and practice-oriented research (cooperation between BMBF and DFG) • Transfers of research outcomes
	Stakeholder dialogue • Involvement of future decision makers • Stakeholder involvement • Decision-support-system • Research needs and interests trade-off between users/researchers and financers (???)

5. How to involve political representatives and practitioners or rather how to gain their interest in research programs?
Considerations to involve implementers
• Must be involved in time • To specifically address problems implementers are dealing with
Considerations researchers must bear in mind
• made-to-measure support programs (including capacity building, connectivity) • researchers to take an interest in development context
Difficulties of involving small and medium-sized businesses and local authorities
• financial involvement • researchers to take an interest in development context • during the writing of the proposal their involvement is too time-consuming (complicated administration and entails uncertainties with regard to decision-making processes within the project) • BMBF should detach itself from ‘hot’ topics • Support through the German Federation of Industrial Research Associations „Otto von Guericke“ e.V. (AiF) is clearly more lucrative than support provided by BMBF

• Better coordination between different authorities (above all BMBF, BMU, BMZ, UBA)

6. Innovations for coordination and marketing mechanisms	
Nr.	**Themes**
	Transdisciplinarity • Knowledge marketing • Translation of research • Decision-support-system • The project team has to be professional referring transdisciplinarity
	Cooperation between researchers and politics • Status seminars • Network creation
	Cooperation between BMBF and DFG
	Adaptive management

6. What must be considered when writing project proposals/planning a project	
Nr.	**Themes**
	• To involve more universities not only major consortiums (UFZ, etc.) • Stakeholder involvement when defining the problem • Linked and clear, targeted concepts for stakeholder involvement • If major consortiums are needed, the problem must be clearly defined • Integration • Sustainability • Research has to be practice-oriented with a strong and meaningful specification of the research focus • practicability • Financing, cost planning (e.g. not every techology is useful in ever country)
6.a What criteria are needed to assess whether proposals incorporate the aforementioned points?	
Nr.	**Themes**
	• in general criteria should be clear from the start, as well as more comprehensive and more meaningful than before • Criteria should be transparent • The BMBF should have a panel of experts, which acts as an advisory board and accompanies projects from the beginning to

	the end • project financing → a list of criteria is needed

6.b How to connect BMBF projects with other research projects (EU FP7, Interreg, DFG, etc.)?

Combination of BMBF and DFG projects

Positive rating

- DFG promotes basic research and BMBF promotes practice-oriented research
- Main potential for supporting national research
- BMBF could link to basic research

Opportunities for improvement

- Positive connection between DFG and BMBF: Connecting bottom-up with top down
- Positive impact on development cooperation → Building a panel for better communication between relevant research areas

Combination BMBF and Interreg projects

Negative rating (100%)

Combination BMBF and EU projects

Negative rating (75%)

- It is difficult to link federal and European projects (because of the administration, coordination, etc.)

Positive rating (25%)

- EU Projects have the same view on research, but a "third level" would be needed to make the connection between the two functional

Opportunities for improvement

- For good coordination appropriate resources are needed
- To access experiences from other projects e.g. cooperations between research areas and twin cities
- Decentralised control → to allocate different duties to different project partners
- Foster networking as an additional project task

To implement a "Third Level"

Negative

- It could be problematic for a third party to become familiar enough with the projects in order to evaluate them

Positive

- A ‚third level' could deal with analyses and evaluations of projects, like

GLOWA, at a higher level. Which research approaches were successful in which context? • The federal government be able to coordinate the ministries
Opportunities for improvement
• Connections between programs, e.g. EU and BMBF, are difficult, but not impossible if they are coordinated by a "Third Level" • It could be problematic for a third party to become familiar enough with the projects in order to evaluate them

6.c positive and negative aspects of linking research support
Negative
• It is problematic to realise the interests of funding authorities → fund receivers must meet these interests • Purely sientific projects → neglecting implematation at a later stage, solutions are often not practicable • Focus on practicable solutions → basic research is often neglected
Positive
• **Focus on practicable solutions → more basic research**

6.d When installing a new research program within German water research, how should this be done?
on the part of BMBF
Stronger cooperation with practitioners • to avoid competition between research projects in research regions • Status seminars • coherence is needed (common assessments (research & technical) presented to the partner) • Building networks
Define country-specific research programs • Interdepartmental planning • long term developments/collaboration • financing follow-up activities • Researchers must be present in their research areas → no remote research
Transdisciplinarity • Addressing research institutions (DFG, etc) and users (environmental policy/-administration, etc.) • Water research must be open to other disciplines • The problem of sustainability → determination of definition, criteria,

evaluation, etc.) • Economic valuation of the water cycle
Project structure • Project structures must be larger, integrative and diversified • Bundled programs • Harmonize strategies e.g. for emerging countries • Better coordination of actors (Development cooperation e.g. cooperation with BMZ)
on the part of the user
• If a proposal includes „sustainability" then it must address this. This leads to a change in the research agenda. Accordingly, specific research approaches can be supported.
in interaction
• **Networking project**: cross-sectional project to promote the communication between projects → Lessons-Learned e.g. RIMAX management of external floodings (GFZ Potsdam) • The BMBF could regulate research through specific financial support; DFG responds to this only

Food and Water: Analysis of potentially new themes in water management - future trends and research needs

November 2009

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Figures

1 Introduction

The German Ministry of Education and Research (BMBF) has funded several major research program on Integrated Water Resources Management and Global Change. Currently, BMBF is in the process to identify promising future research themes by analyzing the international water research and policy landscape and by taking stock of recent achievements.

Based on a preliminary assessment the following themes of high political relevance and major research needs and potential have been identified:
1. Adaptation to climate change
2. Food and water
3. Urbanization and infrastructure
4. Disasters and vulnerability to water related threats
5. Water governance (cross-cutting)
6. Ecosystem water requirements – environmental flows (cross-cutting)

This report contributes to theme 2: Food and Water

This report will cover the following main items (responsible author Peter Droogers / Nick van der Giesen):

- Trends in food demand (PD/NG)
- Rainfed agriculture (PD)
- Irrigated agriculture (NG)
- Water and fishery (NG)
- Water and livestock (PD)

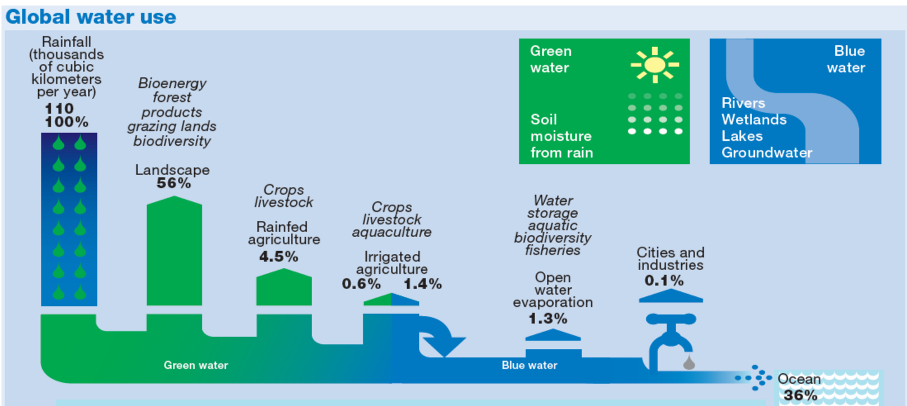

Figure 1. Global water use (source Molden, 2007)

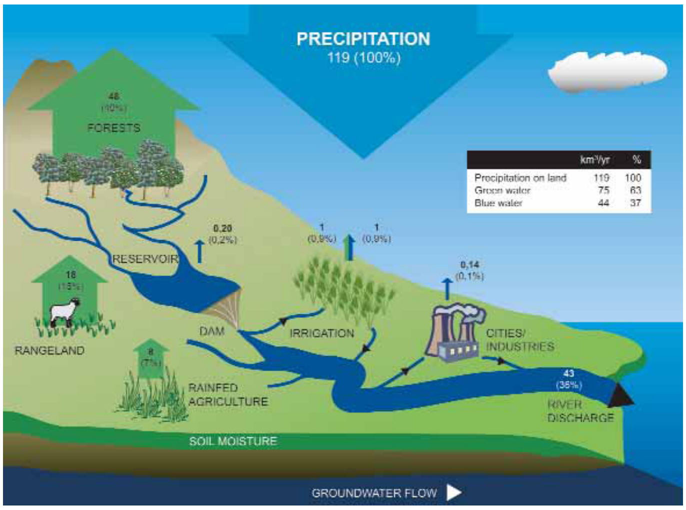

Figure 2. Global water evapotranspiration (source WWAP, 2006)

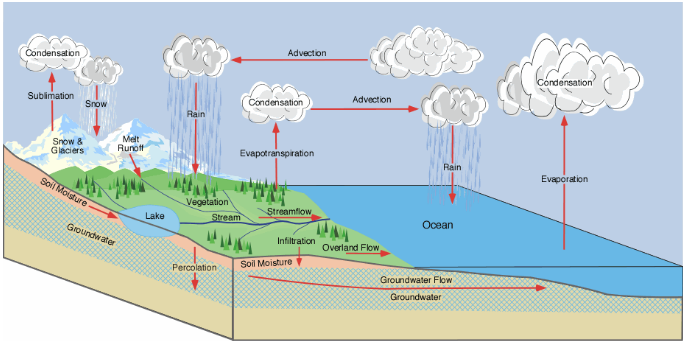

Figure 3. Hydrological cycle (source: Pidwirny, 2006)

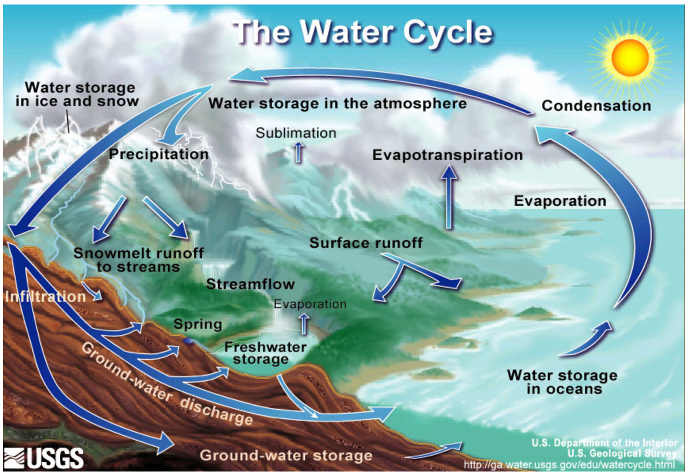

Figure 4. Hydrological cycle (source: USGS)

2 Trends in Food Demand

Various global assessment studies using an integrated approach to water and food exist. The approaches followed by these global studies can be divided into two groups. One the one hand exist studies that have a strong embedding in the economic science where physical (hydrological) processes are to a large extent ignored. In these studies water-food issues are represented by simplified parametric equations and the main driving forces are considered to be the economic ones. These economics are often driven by food demand and food supply. Typical examples include the work of the International Food Policy Research Institute (IFPRI) in Washington.

The other group of global studies on water and food interactions is based on strong hydrological assessment. The economics are assumed of lower importance and often limited to a post-calculation of the agro-hydrological results rather than a driving force. Some typical examples include the work on the so-called AEZ (agro-ecological zones) of the The Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA). A more recent approach is the so-called LPJ-MAgPIE project (Lotze-Campen et al., 2005) based on the Lund-Potsdam-Jena Dynamic Global Vegetation-Model (LPJ) and the “Management model of Agricultural Production and its Impact on the Environment” (MAgPIE) models were coupled. A prototype has been developed for Germany as well (Lotze-Campe et al., 2008).

One common weakness in both approaches is the focus on average conditions. There are hardly any global studies that include the natural year-to-year variation in the analysis, while it is expected that the impact of climate change will alter not only the mean but will have a significant increase on extremes.

An interesting synthesis paper was published recently looking at the global perspective of water and energy inputs in food production (Khan and Hanjra, 2008). The main findings in this review are repeated here:

- Loss of natural habitat on agriculturally usable land (Green et al., 2005).
- Increase in continental water storage formerly flowing to deltas, wetland and inland sinks and its impacts on greenhouse gases (Milly et al., 2003).
- Homogenization of regionally distinct environmental templates/ landscapes, due to excessive construction of dams (Poff et al., 2007), thereby altering natural dynamics in ecologically important flows on continental (Fig. 2) to global scale (Arthington et al., 2006).
- Loss or extinction of freshwater fauna populations and habitat for native fisheries, plummeting population of birds due to inadequate water flows, and loss of riverine biodiversity due to large scale hydrological changes in tropical regions (Dudgeon, 2000).
- Biodiversity loss associated with agricultural intensification (Butler et al., 2007; Kremen et al., 2002).
- Enhanced global movement of various forms of nitrogen between the living world and the soil, water, and atmosphere with serious and long-term environmental consequences for large regions of the Earth (Vitousek et al., 1997).
- Nitrate pollution of agricultural landscapes and groundwater resources, and nitrogen- and phosphorous-driven eutrophication of terrestrial, freshwater, and near-shore marine

ecosystems, causing unprecedented ecosystem simplification, loss of ecosystem services, species extinctions, outbreaks of nuisance species, shifts in the structure of food chains, and contribution to atmospheric accumulation of greenhouse gases (Correll, 1998; Tilman et al., 2001).

- Synthetic chemicals compromising symbiotic nitrogen fixation, thus increasing dependence on synthetic agrochemicals and unsustainable long-term crop yields (Fox et al., 2007).
- Soil salinity and water logging and impaired natural drainage, and associated damages to infrastructure and lost opportunities for regional growth and economic development (Khan et al., 2006; Kijne, 2006; Wichelns and Oster, 2006).
- Depletion of groundwater aquifer and reduced stream flows (Khan et al., 2008a) and associated impacts on drinking water supplies, health and rural livelihoods (Meijer et al., 2006). Displacement of population due to dam construction (Cernea, 2003), and higher incidence of vector-borne diseases in some irrigation areas and loss of human productivity (Lautze et al., 2007).
- Reduced capacity of the ecosystems to sustain food production, maintain freshwater and forest resources, purify water, regulate climate and air quality, or ameliorate infectious diseases (Foley et al., 2005).
- Global accelerated erosion from plowed agricultural fields and hill slope production – greater than 1–2 orders of magnitude than rates of soil production; and erosion under native vegetation, and long-term geological erosion (Montgomery, 2007).
- Erosion caused by human transport of larger amounts of sediment and rocks for construction and agricultural activities exceeding all other natural process operating on the surface of the planet (Wilkinson and Mcelroy, 2007).
- Surge in extreme hydrological events such as storms, droughts and floods (Illangasekare et al., 2006).
- Global, inter- and intra-state conflict over freshwater resources and potential for social instability (Yoffe et al., 2004).
- Raised threat level of global terrorism to water resources due to elevated risk to dams and reservoirs (Gleick, 2006; Mustafa, 2005).

These points mentioned by Khan and Hanjra (2008) can be considered as a starting point when identifying research priorities related to the environmental impact of agricultural production.

3 Rainfed Agriculture

3.1 Introduction

The bulk of the world's agricultural production is rainfed, not irrigated. Despite substantial increases in large-scale irrigation infrastructure over the past half century, the bulk of the world's agricultural production still comes from predominantly rainfed lands. Some 55% of the gross value of crop production is grown under rainfed agriculture on 72% of harvested land (Molden et al., 2007). Approximately 70% of the world's irrigated land is in Asia, where it accounts for almost 35% of cultivated land. Rainfed agriculture is therefore by far the most important agricultural production system in most parts of the world and a major consumer of water by evapotranspiration losses (Figure 5).

The definition whether agriculture is rainfed or irrigated is however very vague (Droogers et al., 2008). A more detailed discussion on the definition of irrigated agriculture is presented in the chapter "Irrigated Agriculture", but in the context of this chapter rainfed agriculture is defined as an agricultural production system where no water will be put artificially on the field. This means that practices as rainwater harvesting are not excluded from rainfed agriculture, as long as this water is stored in the root zone and thus available for the plant without human intervention.

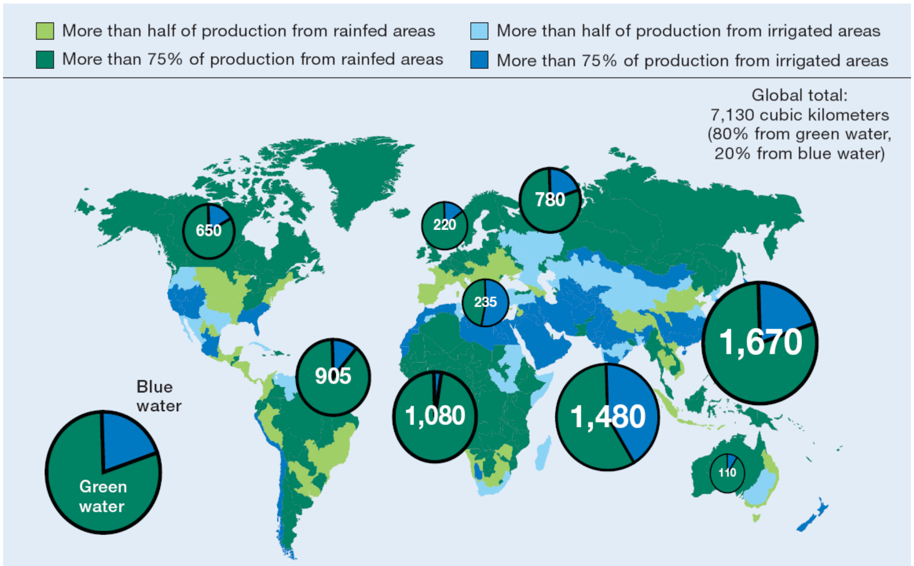

Figure 5. Food crop evapotranspiration from rain and irrigation (source Molden, 2007)

Over the last three years two comprehensive overview studies on water and food have been presented including substantial parts related to water and rainfed agriculture. The first one, Comprehensive Assessment of Water Management in Agriculture (Molden, 2007) describes in 16 chapters the state of the art of water in agriculture in general including rainfed agriculture. The researchers described their activities as

"The Comprehensive Assessment of Water Management in Agriculture critically evaluates the benefits, costs, and impacts of the past 50 years of water development, the water management challenges communities are facing today, and solutions people have developed. The results will enable better investment and management decisions in water and agriculture in the near future and over the next 50 years. The assessment is produced by a broad partnership of practitioners, researchers and policy makers."

The main message of this comprehensive assessment is that if appropriate measures, including research, will be taken, food security can be achieved under current and future conditions. The analysis resulted in eight so-called policy actions, which have implications for setting the research agenda (Molden, 2007):

- 1 Change the way we think about water and agriculture
- 2 Fight poverty by improving access to agricultural water and its use
- 3 Manage agriculture to enhance ecosystem services
- 4 Increase the productivity of water
- 5 Upgrade rainfed systems—a little water can go a long way
- 6 Adapt yesterday's irrigation to tomorrow's needs
- 7 Reform the reform process—targeting state institutions
- 8 Deal with tradeoffs and make difficult choices

Three of those points are focusing specifically on rainfed agriculture:

- **1. Change the way we think about water and agriculture**. Thinking differently about water is essential for achieving our triple goal of ensuring food security, reducing poverty, and conserving ecosystems. Instead of a narrow focus on rivers and groundwater, view rain as the ultimate source of water that can be managed. Instead of blueprint designs, craft institutions while recognizing the politically contentious nature of the reform process. And instead of isolating agriculture as a production system, view it as an integrated multiple-use system and as an agro-ecosystem, providing services and interacting with other ecosystems.
- **4. Increase the productivity of water.** Gaining more yield and value from less water can reduce future demand for water, limiting environmental degradation and easing competition for water. A 35% increase in water productivity could reduce additional crop water consumption from 80% to 20%. More food can be produced per unit of water in all types of farming systems, with livestock systems deserving attention. But this optimism should be met with caution because in areas of high productivity only small gains are possible. Larger potential exists in getting more value per unit of water, especially through integrated systems and higher value production systems and through reductions in social and environmental costs. With careful targeting, the poor can benefit from water productivity gains in crop, fishery, livestock, and mixed systems.
- **5. Upgrade rainfed systems**. Rainfed agriculture is upgraded by improving soil moisture conservation and, where feasible, providing supplemental irrigation. These techniques hold underexploited potential for quickly lifting the greatest number of people out of poverty and for increasing water productivity, especially in Sub-Saharan Africa and parts of Asia. Mixed crop and livestock systems hold good potential, with the increased demand for livestock products and the scope for improving the productivity of these systems.

The second comprehensive studies on water and rainfed agriculture are undertaken by the UNESCO World Water Assessment Programme (WWAP, 2009 and WWAP, 2006) where rainfed agriculture is seen as an important factor in the world food production. The key messages as described in the World Water Development Report (WWAP, 2006) are:

- To satisfy the growing demand for food between 2000 and 2030, production of food crops in developing countries is projected to increase by 67 percent.
- As competition for water increases among different sectors, irrigated agriculture needs to be carefully examined.

- Farmers are at the centre of any process of change and need to be encouraged and guided.
- Irrigation institutions must respond to the needs of farmers, ensuring more reliable delivery of water, increasing transparency in its management and balancing efficiency and equity in access to water.
- The agriculture sector faces a complex challenge: producing more food of better quality while using less water per unit of output.
- Action is needed now to adapt agricultural and rural development policies.

The key messages of the latest report WWDR-2009 are summarized as:

- Population growth and rapid economic development have led to accelerated freshwater withdrawals.
- Trends in access to domestic water supply indicate substantial improvement in the past decade.
- Steadily increasing demand for agricultural products to satisfy the needs of a growing population continues to be the main driver behind water use.
- The recent acceleration in the production of biofuels and the impacts of climate change bring new challenges and add to the pressures on land and water resources.
- Freshwater ecosystems provide an extensive array of vital services to support human well-being.

This latest report of the WWAP included an interesting section on "How much do we know about water uses?" The report provides the following view on this:
"Our knowledge of water use is as poor as our knowledge of water resources – perhaps poorer. Information is largely incomplete – particularly for agriculture, the largest user – and is lacking altogether for some countries. Only limited disaggregated information exists, and even this shows deficiencies of validity and homogeneity and provides extremely poor information on trends. The quality of information systems varies with each country, but there are common difficulties:

- *Statistics on the magnitude of demand and withdrawal are often estimated rather than based on data that are measured or collected from censuses. The level of uncertainty varies, but is particularly high for agriculture.*
- *Sectors of use are not defined homogeneously and are not well disaggregated.*
- *Adequate historical datasets are rare, and the dates of available statistics are not always explicit.*
- *Lack of agreed terminology leads to discrepancies in data compilation and analyses"*

Besides these two all-encompassing studies in which rainfed agriculture is an important theme, a comprehensive study focusing on rainfed agriculture exclusively was published recently: Rainfed Agriculture: Unlocking the Potential (Wani, et al., 2009). The main reason to focus on rainfed agriculture only is justified by the authors since rainfed agriculture is practiced on 80% of the world's agricultural area and generates 60–70% of the world's staple food (FAOSTAT, 2005).

An important question asked by many researchers is whether rainfed agriculture can feed the current and future world population (Fraiture et al., 2009). This quite straight-forward question is so-far un-answered and varies amongst researchers between a clear "yes" to a probably "no". An important aspect in this debate is the relative roles of irrigated and rainfed agriculture. A theoretical study focusing on water resources only, indicated that the current area under rainfed agriculture could be increased by a factor three, under the conditions that all land can be converted to agriculture (Droogers et al., 2001). Rosegrant et al. (2002a) project that more than 50% of additional grain production will come from rainfed areas, particularly in developed countries, while developing countries will increase their imports of grains. Bruinsma (2003) foresees that the contribution to global food supply from rainfed areas will decline from 65% today to 48% in 2030, offset by productivity improvements and irrigated area expansion.

However, referring to mixed results of past efforts to enhance productivity in rainfed areas, Seckler and Amarasinghe (2000) are less optimistic concerning the potential of rainfed agriculture. They foresee that only 5% of the increase in future grain production will come from rainfed agriculture, while the major part will originate from irrigated areas. Further, while numerous studies document the benefits of upgrading rainfed agriculture (Agarwal and Narain, 1999; Wani et al., 2003c), upscaling successes proved challenging. Water-harvesting techniques have long been known, but adoption rates have been low due to low profitability of agriculture, lack of markets, relatively high labour costs and high risks. Yields are highly dependent on economic incentives and crop prices, and a high-yield scenario will only happen if it is profitable for individual farmers (Bruinsma, 2003). Others counter that compared with irrigated agriculture, investments in rainfed agriculture have been very small, mainly targeted to soil conservation rather than water harvesting (Rockström et al., 2007; Wani et al., 2009). It is also suggested that particularly in sub-Saharan Africa, irrigation investments have been a mixed success and that therefore focus should be more investments in rainfed agriculture. A study by Inocencio et al. (2006) reports a success ratio of 50% for new irrigation projects in sub-Saharan Africa.

A SCOPUS search on the keyword “rainfed” in the title for the years 2008 and 2009 indicates relevant Journals (in brackets number of articles):

- Agricultural Water Management (19)
- Field Crops Research (15)
- Indian Journal of Agricultural Sciences (13)
- Agriculture Ecosystems and Environment (8)
- Agronomy Journal (6)
- Soil and Tillage Research (5)
- Agricultural and Forest Meteorology (5)
- Journal of Agricultural Science (4)
- Journal of Plant Registrations (4)
- Nutrient Cycling in Agroecosystems (4)
- Plant and Soil (4)
- Physics and Chemistry of the Earth (3)

The main research issues regarding rainfed agriculture can be divided into the following categories and will be discussed in the next sections:

- Global scale
- Local scale
- Yield gap
- CO_2 fertilizer

3.2 Global scale

Quite a substantial number of studies have been undertaken over the last two decades related to rainfed agriculture, food and water. In fact the first global assessment on global food supply and demand was published by Thomas Robert Malthus in 1798, who famously predicted that short-term gains in living standards would inevitably be undermined as human population growth outstripped food production. However, the more recent scenario studies at the global level indicate that the potential of rainfed agriculture is large enough to meet present and future food demand through increased productivity (Molden, 2007). An optimistic rainfed scenario assumes significant progress in upgrading rainfed systems while relying on minimal increases in irrigated production, by reaching 80% of the maximum obtainable yield. This leads to an average increase of yields from 2.7 metric tons per hectare in 2000 to 4.5 in 2050 (1% annual growth). With no expansion of irrigated area, the total cropped area would have to increase by only 7%, compared with 24% from 1961 to 2000, to keep pace with rising demand for agricultural commodities. The same study indicated also that focusing only on rainfed areas carries considerable risks. If adoption rates of improved technologies are low and rainfed yield improvements do not materialize, the expansion in rainfed cropped area required to meet rising food demand would be around 53% by 2050. Globally, the land for this is available, but agriculture would then encroach on marginally suitable lands and add to environmental degradation, with more natural ecosystems converted to agriculture (Molden, 2007).

There are only few global studies focus on rainfed agriculture. An interesting example of this was presented by Rockström and Barron (2007) where they analyzed the option to increase crop yields while at the same time maintain water consumption at a constant or lower rate. Focus on increasing the so-called Water Productivity was considered as a key factor. In their research the Millennium Development Goals as established at global scale level were linked to practical management options and additional research needs as local scale. They strongly recommended that further research is required on Water Productivity of rainfed agriculture.

Rost et al. (2009) presented, what they claim, one of the first studies focusing on a spatially explicit quantification of water limitations in global crop production and the potential of different water management strategies to upgrade crop growth, under both present and projected future climate conditions. The study indicated that even the most ambitious and large-scale water management efforts on present cropland will not be sufficient to guarantee the food demands of a growing world population. This result is quite in contrast with most other studies (Molden, 2007; WWDR, 2006; WWDR, 2009; Rosegrant et al., 2009). A nice overview of these global assessments studies was published in Science by Rosegrant and Cline (2003).

3.3 Local scale

Researches on rainfed agriculture on smaller scales are focusing often limited to field scale issues only and to specific crops. The intermediate scale, like basins or watershed, is by enlarge ignored. Typical examples can be obtained by a search in recent scientific literature (using SCOPUS), on the keyword “rainfed”. The following 10 titles of the most recent research papers are:

- Modelling the fate of nitrogen following pig slurry application on a tropical cropped acid soil on the island of Réunion (France)

- Response of lowland rice to agronomic management under different hydrological regimes in an inland valley of Ivory Coast
- Runoff water harvesting for dry spell mitigation for cowpea in the savannah belt of Nigeria
- Carbon losses by tillage under semi-arid Mediterranean rainfed agriculture (SW Spain)
- Role of temperature, moisture and Trichoderma species on the survival of Fusarium oxysporum ciceri in the rainfed areas of Pakistan
- Estimating the potential of rainfed agriculture in India: Prospects for water productivity improvements
- Nitrogen in Rainfed and Irrigated Cropping Systems in the Mediterranean Region
- Soil texture, climate and management effects on plant growth, grain yield and water use by rainfed maize-wheat cropping system: Field and simulation study
- Frequency of occurrence of various drought types and its impact on performance of photoperiod-sensitive and insensitive rice genotypes in rainfed lowland conditions in Cambodia
- Influence of conservation tillage on soil physicochemical properties in a tropical rainfed agricultural system of northeast India

Regarding the regional and local focus it is clear that most research on rainfed agriculture is focused on arid and semi-arid areas, while ignoring by enlarge the humid regions. However, there is a growing notice that water shortage is an important topic in humid regions as well. The 2003 Europe Heat Wave for example resulted in a fodder deficit varied from 30% (Germany, Austria and Spain) to 40% (Italy) and 60% in France and the fall in cereal production in EU reached more than 23 million tonnes (MT) as compared to 2002 (UNEP, 2003). Agricultural losses were estimated at 5 billion Euros across the then 15-member EU (http://www.euronews.net).

3.4 Yield gap

An important issue in research in rainfed agriculture is the so-called yield-gap (Molden, 2007; Fermont et al., 2009; Aggarwal et al., 2008). Yield gap is in general defined as “the difference of actual yield and yield obtained under optimum management practices”. However, some researchers take a somewhat more restricted eco-system oriented definition as “yields determined by the land-based natural resources” (Bindraban, 2000). The latter one assumes that no additional fertilizer or irrigation will be applied. The first definition is more accepted and will be used here.

Yield gap studies can be divided into two categories. The first category takes the actual obtained maximum yields on well-managed fields in a region as the basis. These fields are often experimental fields or farmer fields who manage to obtain highest yields in a region (Kalra et al., 2007; Fermont, 2009). Another approach is to assess the maximum yields in a particular region for a particular crop using simulation models (Bhatia et al., 2008; Abeledo et al., 2008).

Most of the studies conclude that closing, or reducing, this yield gap might be the best option to ensure food security for a growing population under water limited conditions. Although most of the yield gap studies are very local, FAO (1996) analyzed the yield gap at a global scale (Figure 6). This study is quite outdated and it is necessary to renew the analysis taking into account more recent data sets, analysis and tools.

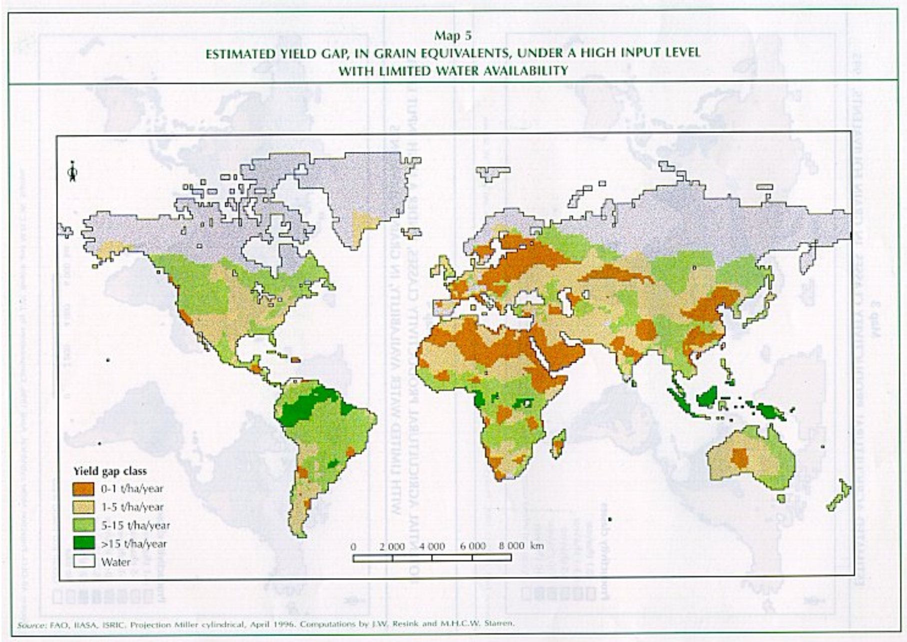

Figure 6. Global yield gap estimates (FAO, 1996)

3.5 CO_2 fertilization

An important aspect in the potential of rainfed (and irrigated) agriculture is the impact of enhanced CO_2 levels on plant growth and water consumption. An interesting review, although somewhat outdated, of this CO_2 fertilization is presented by Bazzaz and Sombroek (1996). They mention that the rise in atmospheric carbon dioxide (CO_2) concentration from about 280 ppm before the industrial revolution to about 360 ppm currently is well documented (e.g., Baker and Enoch, 1983; Keeling et al., 1995). The consensus of many studies of the effects of elevated CO_2 on plants is that the CO_2 fertilization effect is real (see Kimball, 1983; Allen, 1990; Rozema et al., 1993). However, the CO_2 fertilization effect may not be manifested under conditions where some other growth factor is severely limiting, such as low temperature (Long, 1991).

Interesting is that a recent study from the International Food Policy Research Institute (Nelson et al., 2009). In their executive summary it was stated that *"Calorie availability in 2050 will not only be lower than in the no–climate-change scenario—it will actually decline relative to 2000 levels throughout the developing world"*. However, this conclusion is based on changes in rainfall and temperature only, ignoring the effect of CO_2 fertilization. This is interesting as it is well agreed that changes in CO_2 levels are considered as the most certain compared to other changes. The study results indicated that if CO_2 fertilization will be included in the analysis daily per capita calorie availability will increase in developing countries by 5.7%

On crop scale a substantial number of researches have been undertaken to analyze the impact of CO_2 fertilization on yields (http://www.co2science.org/). A typical example based on 222 published papers is presented in Figure 7 for one particular crop. There is however a huge knowledge gap as what the impact might be on crop water consumption. Atmospheric CO_2 enrichment may stimulate plant growth directly through (1) enhanced photosynthesis or indirectly, through (2) reduced plant water consumption and hence slower soil moisture depletion, or the combination of both. Morgan et al. (2004) concluded, based on a substantial number of research, that the central question is as to what degree CO_2 enrichment experiments produce direct CO_2 (photosynthesis-driven) responses vs. indirect, water-driven responses, The latter ones being tightly coupled to climatic co-variables like temperature and humidity.

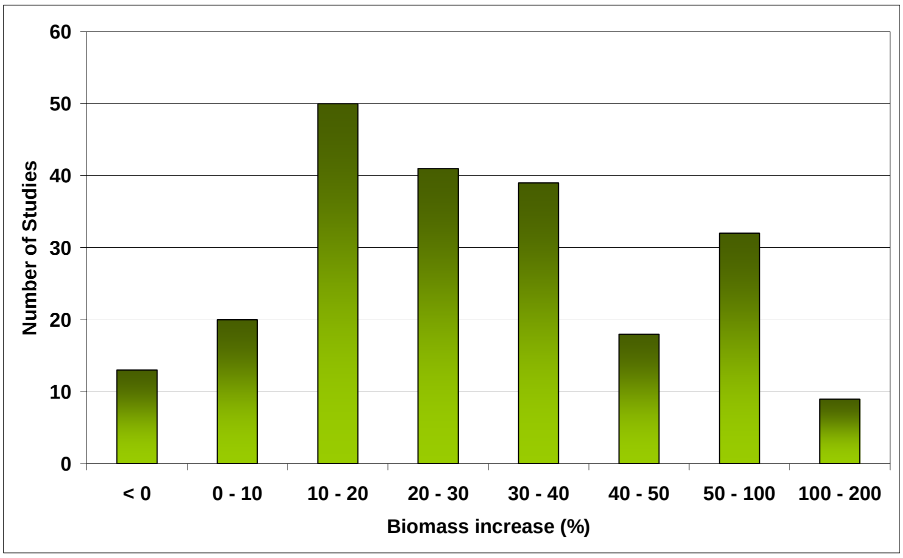

Figure 7. Percent biomass increases for 300 ppm increases in CO_2 concentration for wheat, based on 222 publications. (Source: http://www.co2science.org)

3.6 Research Issues

Based on the previous sections the most important research issues regarding Water and Rainfed Agriculture are summarized here

3.6.1 Global opportunities rainfed agriculture

There is still a scientific debate on the potential of rainfed agriculture to feed the world in the future. Some research suggests that this potential is sufficient to feed the expected 9 billion world population while other studies indicate severe food shortages. These differences are often a reflection of different assumptions, often in terms of limiting factors in rainfed production, in the analysis. Research is therefore needed with a clear focus and appropriate definitions on these limitations. Analysis should therefore start with the full potential of rainfed agriculture, assuming no limitations at all. Stepwise, limitations would be added on this potential such as: water, land, investments, farmer knowledge, climate change etc.

3.6.2 Local scale

Research issues on water and rainfed agriculture are so-far mainly oriented towards arid and semi-arid areas with a focus on rainwater harvesting. There is a clear need for studies that will include the following four integrated components: (i) humid areas, (ii) expand the very local focus to more generic conclusions, (iii) impact of rainwater harvesting on downstream water users, and (iv)water productivity.

3.6.3 Yield gap

Closing the yield gap is seen as an important aspect to increase food production and reduce water consumption by crops. Two promising and unexplored research themes can be identified. First, yield gap research is in many cases very local, crop specific and more descriptive. There is a clear need to upgrade yield gap studies at a higher conceptual level based on fundamental deductive analyses. A second research need is yield gap analyses at larger scale levels (regions) with a strong emphasis on water issues including impact on other water users in the region.

3.6.4 CO_2 fertilization

It is clear that atmospheric CO_2 enrichment may stimulate plant growth directly through (1) enhanced photosynthesis or indirectly, through (2) reduced plant water consumption or (3) the combination of both. Studies are very much needed that will provide an answer on the contribution of CO_2 fertilization on water consumption of crops.

4 Irrigated Agriculture

[To be included: Nick van der Giesen]

4.1 Area under irrigation

Irrigated agriculture is on a global scale responsible for somewhere between 30 and 45% of the total food production (Molden et al., 2007). The exact figure is unknown as this depends by enlarge on the definition of irrigated. A commonly used definition is “Area equipped for irrigation” (FAO-AQUASTAT), which can be substantially different from reality. Moreover, there seems to be a tendency, especially in the developed world, as a result of the negative image of irrigation, to frequently use terms like rainfall harvesting and supplemental irrigation rather than irrigation. This is clearly illustrated through the following definitions from Oweis et al. 1999:

- “Water harvesting (WH) is defined as the process of concentrating rainfall as runoff from a larger area for use in a smaller target area.”
- “Supplemental irrigation (SI) is defined as the application of a limited amount of water to the crop when rainfall fails to provide sufficient water for plant growth to increase and stabilize yields.”

Without any doubt, these two descriptions would have been defined as “full irrigation” a decade ago. Another example of this problem with definitions is that according to FAO statistics the percentage of agricultural land under irrigation[1] in the Netherlands is 37 percent, while this figure for Germany is 4% and for Belgium 2% (FAO-Aquastat, Country factsheets). The likely cause is that some limited sprinkling of fields during dry summers is possibly counted as irrigation in the Netherlands and not in Germany and Belgium.

Cai et al. (2007) made a strong case that separating irrigated and rainfed agricultural data is required in order to calculate economic performance of irrigated/rainfed agriculture and irrigation water consumption from irrigated lands. They have developed and tested a method to separate harvested area and yield for irrigated crops from rainfed crops in a region, given gross harvested area and yield, and climatic, agronomic and economic data for crops. The method is based on the principle of general maximum entropy, which combines incomplete data, empirical knowledge and a priori information to derive desired information.

The first shortcoming is that estimates are based on official figures, rather than actual areas. Deviations in the official statistics can differ from the real irrigated areas due to several reasons. It is very common that only water users who pay for their water are registered as irrigators. A study in Turkey revealed for example that the officially reported irrigated areas were only 58% of the actual irrigated areas on a basin scale, while at irrigation system level figures range from 50% to 86% (GDRS/IWMI, 2000). The main reason for this was that farmers not paying for water, such as those using groundwater and ‘illegal’ extractions, were ignored in the statistics. Recently, Bastiaanssen et al. (2001) showed that for Pakistan the difference between official irrigated areas and actual irrigated areas could be more than 100% at canal command area level.

A second problem is the definition of irrigation.

[1] Official definition is “total area equipped for irrigation as percentage of cultivated area”

A third aspect, related to the definition problem, is the time period for which fields are actually irrigated. From a water resources point of view it is essential to know the period when fields are really irrigated. However, most figures present this as simply “irrigated”—with no reference to time.

5 Water and Fishery

[To be included: Nick van der Giesen]

6 Water and Livestock

6.1 Background

The term livestock refers to "animals kept or raised for use or pleasure; especially**:** farm animals kept for use and profit" (Webster dictionary). In this report only the restricted use of the term livestock "farm animals kept for use and profit" will be discussed.

Livestock have always made a major contribution to the welfare of human societies by providing food, shelter, fuel, fertilizer and other products and services. They are a renewable resource, and utilize another renewable resource, plants, to produce these products and services. In addition, the manure produced by the animals helps improve soil fertility and, thus, aids the plants. In some regions the manure is not utilized as a fertilizer but is dried as a source of fuel.

Food is, by far, the most important contribution of agricultural animal, although they rank well behind plants in total quantity of food supplied. Plants supply over 80 percent of the total calories consumed in the world. Animals are a more important source of protein than they are of calories, supplying one-third of the protein consumed in the world. Meat, milk and fish are about equal sources of animal protein, supplying, respectively, 35%, 34% and 27% of the world supply of total protein (OSU, 2009).

Although livestock are less important in terms of calorie provider, in terms of impact on land livestock play a dominant role. According to FAOstat (2009), almost 70% of the agricultural lands are in use as permanent meadows and pastures (Table 1). This figure various substantial between countries and continents, ranging from 38% for Europe to 79% for Africa (Figure 8).

Given this dominancy of livestock in terms of land use, livestock is definitely an important factor related to water. A very good introduction on water and livestock for human development is given by Peden et al., (2007), with a strong focus on the developing world.

The link of water and livestock is in many researches considered as the actual amount of water drunk by animals. These so-called direct water requirements of livestock vary substantially between different animals. Typical numbers are 2 to 10 liter per day per sheep, 25 to 100 liters per day per cow, and 40 to 50 liter per day per horse (Markwick 2002). Moreover, livestock in general cannot withstand long periods without water with the exception of camels. The camel has a legendary reputation to withstand relatively long periods of water deprivation under hot conditions even up to 17 days (Fillali & Shaw 2004). In water resources projects in Africa the notion of including livestock drinking water requirements is often ignored in project leading to potential or actual conflicts over water in rural communities (Gleitsmann et al. 2007).

A very rough first estimate of this direct water consumption can be made by multiplying the estimated water requirements by the total number of stock (Table 2). The figures show that this amount is approximately 100 MCM per day on a global scale. Compared to global human drinking water needs of 12 MCM per day (assuming 2 l/p/d), the drinking water requirement of livestock at global scale is relatively high. However, total urban water requirements, including sanitation needs, are about 600 MCM per day (assuming 100 l/p/d) and are thus substantially higher than drinking water needs for livestock. However, quite some of these total urban water requirements are drained and can be reused.

Besides these global figures, the regional distribution of livestock drinking water requirements and regional water availability can be far out of balance. Especially if the temporal timescale will be added on top of this, drinking water for livestock can be very problematic. Studies on the relationships between number of livestock and water availability show always, not very surprisingly, a strong correlation (e.g. Bergstrom and Skarpe, 1999).

An important aspect of livestock and water requirements is that in many farming systems animals are vital parts for survival. The predominant farming system in most semi-arid watersheds in Asia and Africa is the ‘mixed crop-livestock farming system’ under rainfed conditions (Puskur et al. 2004). Especially in the more water stressed regions, the competition of human and animal for drinking water can be severe and might result in killing part of the livestock of a household. A typical example was given by (Sen & Chander 2003) for Rajasthan, India, for the drought in 2002. In three years time villages had just one-fifth of the livestock they had three years ago, and the price of buffaloes had come down from INR 15,000 (approximately US$320) to only INR 800 (approximately US$17).

The real issue in livestock water requirements is actually the production of fodder required to feed animals. This is comparable to humans where the drinking water requirements only are limited to a few liters a day and the water required to produce food is in the order of 3000 to 5000 liters per person per day. However, it is impossible to find accurate data on these total water requirements of livestock. Much popular and environmental literature considers livestock production to be among the greatest threats to sustainable water use over the coming decades (Peden et al., 2007). The large volumes of water necessary to produce human food from livestock are the major concern. For example, the Times of India (2004) reported that one liter of milk requires 3,000 liters of water, and attributes to rapid declines in groundwater levels. Goodland and Pimental (2000) and Nierenberg (2005) state that producing 1 kilogram (kg) of grainfed beef requires about 100,000 liters of water, while producing 1 kg of potatoes takes only 500 liters. However, SIWI and others (2005) estimate that grainfed beef uses only 15,000 liters of water. Thus, while there is little agreement on the precise amount of water needed for grainfed beef production, the literature does agree that it takes much more water to produce 1 kg of grainfed beef than 1 kg of crops (Chapagain and Hoekstra 2003; Hoekstra and Hung 2003).

A different view is presented by some lobbyist. For example, the website “www.BeefFrom PastureToPlate.org” claims that meat production is not wasteful to water:
“The activist myth goes something like this: meat production uses outrageous amounts of water, feed and land that should be used for something else. The truth is it takes 2.6 pounds (~ 1.2 kg) of grain and 435 gallons (~ 1600 liters) of water to produce a pound (~0.45 kg) of beef in the United States. The reality is that 85 percent of the nation’s grazing lands are not suitable for farming. It is important that we use land that is too rough, too high, too dry, too wet and largely inaccessible to graze livestock to produce food for the world’s population. Cattle eat forages that humans cannot consume and convert them into a nutrient-dense food.”

Interesting is that most global water studies ignore the amount of water required to produce fodder (Zimmer and Renault 2003). In some cases it is specifically mentioned that this water consumption is not included (Zimmer and Renault, 2003), while in most cases it is just ignored at all. There are three reasons for this: (i) ignorance, (ii) difficulty to quantify this value, and (iii) the usefulness of this number. In the context of virtual water, and thus the potential implication of using fodder-water to fulfill other demands, there are conceptual problems. The potential water savings imbedded in imported food will only materialize locally, if the decrease in food production frees up local water resources that can be made available for other uses. This is however not always the case. Some water used for crops and food products cannot be substituted with another use of water, as for instance in the case of cattle which feed on natural rainfed pasture. Livestock in many relative dry regions are taking advantage of a huge territory where little rain can still produce food or fodder, but would otherwise be lost for production. Any attempt to reduce water consumption will not be relevant as the water could never be used for another purpose nor is any other production possible given the limited rains (Renault, 2002).

Water and livestock research in the developing world is often related to water quality and especially to groundwater pollution by nutrients, with a focus on nitrogen. In the European context various resolutions are important including (EC, 2009):

- Nitrates Report - COM(2007)120
- Annexes to the Nitrates Report - SEC(2007)339
- Directive 91/676/EEC on nitrates from agricultural sources
- Report COM(2002)407
- Eutrophication and health

The European Community has been taking measures concerned with nitrogen pollution in waters for over twenty years. Whilst the initial directives concerned themselves mainly with water for human consumption, more recent directives, such as those on nitrates from agricultural sources and urban waste water treatment have placed increased emphasis on the environmental effects of excess nitrogen, in particular eutrophication. These recent directives are currently in the process of implementation.

Water and livestock is also related to the EU Common Agricultural Policy and the wish to integrate environmental concerns as well. The relationship between agriculture and the environment is not static. Agriculture has intensified and intensification in turn has increased pressure on the environment. The European Commission is particular interested in developing a system under the overall term of "sustainable agriculture". This calls for management of natural resources in a way which ensures that their benefits are also available for the future. The agriculture sector performs its tasks with a view to the protection, preservation and improvement in the quality of water, air and soil, in the abundance of bio-diversity and in preservation and enrichment of the EU's landscape.

There is however a big debate within Europe on how to implement these policies and what the scientific base is (Sonneveld and Bouma, 2003). Especially the national implementation of these directives and the spatial diversification on these regulations is an unexplored area (Bouma and Droogers, 2007).

It is clear that European policies are an important driver to science directions and funding. Total FP7 funding is 51 Billion Euros over 7 year, of which Food, Agriculture and Fisheries, and Environment receive about 12%.

6.2 Research Issues

Based on the previous section the most important research issues regarding Water and Livestock are summarized here:

6.2.1 Livestock and water productivity

The concept of water productivity has gained quite some attention over the last years, but is still largely unexplored in the context of livestock. This livestock water productivity does include all water use so direct drinking as well as water required to produce feed. Obviously, this item is mainly relevant in areas where water is scarce. The following research activities are relevant:

- Global scale assessment of livestock water productivity with strong emphasis on spatial and temporal resolution.
- Assessment of the possibility of alternative use of livestock water consumption in semi-arid regions

6.2.2 Livestock and water quality

Especially in the developed world livestock is seen as an important polluter of water. Policies are defined and strict regulations are being implemented. However there is a debate whether these regulations take into account local specific conditions. Based on this chapter the following two research areas are relevant in the broad context of livestock and water quality:

- Impact of livestock on water quality is a completely unexplored area in the developing world. Research might identify potential problems which might lead to policies before severe damage will take place.
- Regional distributed research on the impact of livestock on water quality.

Table 1. Distribution of land between arable and pastures (FAOstat, 2009).

	Total land million ha	Agriculture % of total land	Arable	Permanent crops	Permanent pastures
			===== % of agricultural lands ====		
Africa	2964	39	19	2	79
Northern America	1867	26	45	2	53
Central America	245	52	24	4	72
South America	1760	33	19	2	78
Asia	3094	54	30	4	66
Europe	2207	21	59	3	38
Australia and New Zealand	795	55	10	0	90
World	**12932**	**38**	**29**	**3**	**69**

Table 2. Number of animals on a world scale (FAOstat, 2009) and estimated drinking requirements.

Animals	Stocks (millions)	Drinking (l/d/stock)	Total (million m3 / day)
Chickens	17863	0.2	4
Cattle	1357	50.0	68
Ducks	1096	1.0	1
Sheep	1087	5.0	5
Pigs	918	5.0	5
Goats	830	5.0	4
Turkeys	473	1.0	0
Geese and guinea fowls	343	1.0	0
Buffaloes	177	50.0	9

Beehives	64	0.0	0
Horses	59	40.0	2
Asses	42	10.0	0
Camels	24	10.0	0
Other Rodents	17	10.0	0
Mules	12	10.0	0
Other Camelids	7	10.0	0
Animals Live Nes	6	0.0	0

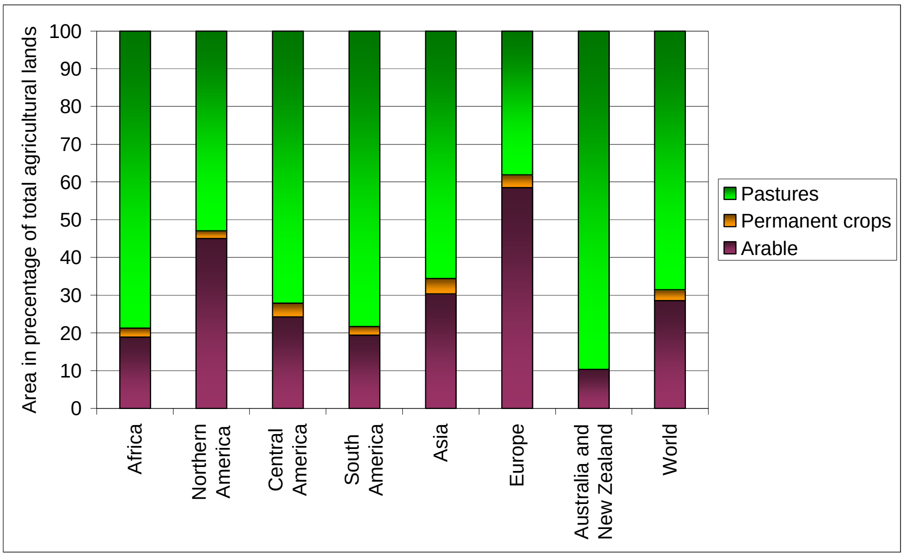

Figure 8. Land under pasture, permanent crops and arable expressed as percentage of total agricultural lands.

7 Synoptic overview of research issues

1. Trends in food demand

Food production will have to increase by 1-2% per year for the next generation in order to keep up with food demand. Increase in food demand is caused by a combination of population growth and changes in consumption patterns, especially an increase in animal-based protein in our diets (Liu & Savenije, 2008). The production of biofuels may, until the advent of so-called third generation biofuels, put extra stress on grain and sugar production. The spike in food prices in 2008 (see Figure 9) has dampened but food prices are still 70% higher than they were five years ago. It has been known for a long time that the supply elasticity of food is low. World trade without dramatic productivity rises can, therefore, only be a limited solution.

There are many direct links between food production and water. In this report, we distinguish four areas:

1. Rainfed agriculture
2. Irrigated agriculture
3. Fresh water and fishery
4. Water and livestock

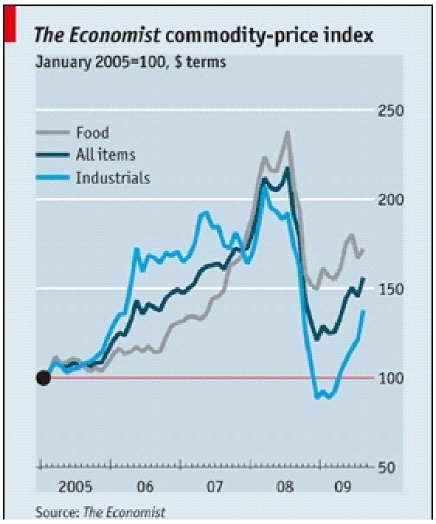

Figure 9. Commodity price development.

Research issue 1.1

Global analysis of food production and its dependency on water

Various global assessment studies using an integrated approach to water and food exist. The approaches followed by these global studies can be divided into two groups. One the one hand exist studies that have a strong embedding in the economic science where physical (hydrological) processes are to a large extent ignored. In these studies water-food issues are represented by simplified parametric equations and the main driving forces are considered to be the economic ones. These economics are often driven by food demand and food supply.

One common weakness is the focus on average conditions. There are hardly any global studies that include the natural year-to-year variation in the analysis, while it is expected that the impact of climate change will alter not only the mean but will have a significant increase on extremes. There is need for a global model that maps future food productivity with sufficient realistic detail. The dependence on water for each production type needs to be analyzed.

Research issue 1.2
Role of trade and virtual water
Richer countries have not been self-sufficient in their food supply for a very long time. Especially the poor in the world have suffered from recent food price increases. The possibility for densely populated poor countries to increase their food production is not a given. The question then becomes where the extra food needed can be grown and if trade can ensure delivery to those who need it most. The water needed to produce these commodities is called "virtual water" and many studies have been undertaken that map the virtual water content of goods and map global flows (Hoekstra & Chapagain, 2008). A global optimization of food production from a water perspective would be an important next step towards good water governance.

2 Rainfed agriculture

The most important research issues regarding Water and Rainfed Agriculture based on the evaluations as described in Chapter 3 are:

Research issue 2.1
Global opportunities rainfed agriculture
There is still a scientific debate on the potential of rainfed agriculture to feed the world in the future. Some research suggests that this potential is sufficient to feed the expected 9 billion world population while other studies indicate severe food shortages. These differences are often a reflection of different assumptions, often in terms of limiting factors in rainfed production, in the analysis. Research is therefore needed with a clear focus and appropriate definitions on these limitations. Analysis should therefore start with the full potential of rainfed agriculture, assuming no limitations at all. Stepwise, limitations would be added on this potential such as: water, land, investments, farmer knowledge, climate change etc.

Research issue 2.2
Local scale
Research issues on water and rainfed agriculture are so-far mainly oriented towards arid and semi-arid areas with a focus on rainwater harvesting. There is a clear need for studies that will include the following four integrated components: (i) humid areas, (ii) expand the very local focus to more generic conclusions, (iii) impact of rainwater harvesting on downstream water users, and (iv)water productivity.

Research issue 2.3
Yield gap
Closing the yield gap is seen as an important aspect to increase food production and reduce water consumption by crops. Two promising and unexplored research themes can be identified. First, yield gap research is in many cases very local, crop specific and more descriptive. There is a clear need to upgrade yield gap studies at a higher conceptual level based on fundamental deductive analyses. A second research need is yield gap analyses at larger scale levels (regions) with a strong emphasis on water issues including impact on other water users in the region.

Research issue 2.4

CO2 fertilization

It is clear that atmospheric CO_2 enrichment may stimulate plant growth directly through (1) enhanced photosynthesis or indirectly, through (2) reduced plant water consumption or (3) the combination of both. Studies are very much needed that will provide an answer on the contribution of CO_2 fertilization on water consumption of crops.

3 Irrigated agriculture

Increased food production can potentially be achieved by different routes but the role that irrigation needs to play is important to understand. Based on the evaluations described in Chapter 4, the following research issues can be identified.

Research issue 3.1

Global opportunities irrigated agriculture

The 2008 spike in food prices coincided with the end of a period of approximately twenty years during which there was almost no growth in irrigated area. This increase in food process has prompted the World Bank to resume investments in irrigation development. It is probably unlikely that the needed increase in food production can be achieved without significant increases in irrigated agriculture. An obvious and important question then becomes where in the world such development can and/or should take place.

Less densely populated areas (Americas, sub-Saharan Africa, Central Asia) would seem to be the most obvious candidates but each region has important drawbacks. In North America, irrigated agriculture seems to have peaked and further expansion there is unlikely due to declining groundwater tables (Ogallala aquifer) and environmental flow requirements. Expansion of (irrigated) agriculture in South America may come at the cost of important losses in bio-diversity rich ecosystems. Central Asia has seen a decline in irrigation development since the breaking up of the Soviet Union and does not have a good environmental track record either. Africa, and especially the savanna zones, may be the most promising from a physical point of view but earlier attempts have stranded in issues of poor governance and low returns on investments. A quantitative analysis of potential irrigation development and associated drawbacks would be a first step towards a better understanding of the food and water issue.

Research issue 3.2

Stressors on irrigated agriculture

Throughout the world, we see examples of a decline in irrigated areas due to unsustainable practices within, and external pressures from without irrigated agriculture. Depletion of groundwater is perhaps the most urgent stressor. Both the Indo-Gangetic and North China plains show water tables declining at alarming rates. Large scale trans-basin water transfers are seen as possible solutions but it is doubtful such measures can be much more than partial fixes. Decline in water and soil quality through accumulation of salts and agro-chemicals is a second important stressor. Thirdly, in many densely populated areas in the world, such as the rice growing areas of Asia, irrigated agriculture declines due to urban expansion. Finally, the competition for water from other sectors increases further, not only due to urban and industrial development, but also because of the higher value put on environmental water uses. The West of the United States is a clear example. The gravity of all different stressors and their development over time and space would be an important research theme.

Research issue 3.3

New technologies for irrigated agriculture

Irrigation is about as old as sedentary agriculture and no miracle technologies are to be expected. Still, the efficiency of irrigated agriculture can be greatly enhanced by supporting technologies. Genetically Manipulated Organisms may be helpful to reduce water demands but early results for GMO maize have been somewhat disappointing, showing only relatively small increases in production under water stressed growing conditions. In arid areas, water re-use will continue to increase but research on better water and soil treatment methods remains needed. Precision agriculture, from plant to parcel scale, will increase water productivity and reduce environmental stress through better control on accumulation of agro-chemical and salt. Remote sensing and ubiquitous sensing will be important technologies to improve irrigation efficiencies.

4 Fresh water and fishery

Research issue 4.1

Value of fresh water fisheries, especially in developing countries

The value of fresh water fish has for a long time been neglected. For most inhabitants of developing countries, however, fish is the main source of animal protein. An early example that showed the importance of fisheries was provided by Ringler (2001) for the Mekong River. All alternative water uses in the Mekong, including hydropower, had lower economic returns than the present fisheries. The global importance of fresh water fisheries, and their effects on diets of people in developing countries, is not yet clear. Over the past decades, many developing projects have tried to improve fish production. Scientific analysis at regional to global scales, including yield gaps, is still needed.

5 Water and livestock

The most important research issues regarding Water and Livestock as emerging from the analysis in Chapter 6 are:

Research issue 5.1

Livestock and water productivity

The concept of water productivity has gained quite some attention over the last years, but is still largely unexplored in the context of livestock. This livestock water productivity does include all water use so direct drinking as well as water required to produce feed. Obviously, this item is mainly relevant in areas where water is scarce. The following research activities are relevant:

- Global scale assessment of livestock water productivity with strong emphasis on spatial and temporal resolution.
- Assessment of the possibility of alternative use of livestock water consumption in semi-arid regions

Research issue 5.2

Livestock and water quality

Especially in the developed world livestock is seen as an important polluter of water. Policies are defined and strict regulations are being implemented. However there is a debate whether these regulations take into account local specific conditions. Based on this chapter the following two research areas are relevant in the broad context of livestock and water quality:

- Impact of livestock on water quality is a completely unexplored area in the developing world. Research might identify potential problems which might lead to policies before severe damage will take place.
- Spatially distributed research on the impact of livestock on water quality.

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Correlations between societal indicators and environmental indicators and observed changes

Birgitta Malm Renöfält

We analyzed correlations between a number of societal and biological indices. These indices represented five major categories; ecological, water quality and water stress, pressures, Socio-political and environmental management (Tab. 1). No clear patterns were found between social indexes and purely ecological indexes. A major problem is that comprehensive global data on freshwater biodiversity is in short supply. In substitute for direct ecological data we looked at indexes representing water quality and water stress, including both water shortage and flow regulation.

We found a significant negative correlation ($R=0.59$, $p<0.001$) between the Natural Resource Management Index (NMRI[1]) and the Corruption Perception Index (CPI[2]), with countries perceived as more corrupt (lower CPI values) being worse off in terms of natural resource management (Fig. 1). This is hardly surprising results, and confirms previous studies on correlations between Environmental Sustainability Index (ESI) and corruption (Morse 2006). Ewers and Smith (2007) showed that opposite conclusions can be drawn once a different index, the Ecological Footprint (EF), is introduced. Their correlations showed that the most sustainable nations under the ESI are the least sustainable under the EF. The EF concept however, is more tied to consumption patterns of individuals irrespective of origin of the resource rather than management of a country's own resources, and the apparent contradiction could imply consumption patterns in some countries affects environmental sustainability in others.

Corruption is also correlated to a number of water quality indices (data availability low however) with more corrupt countries having a lower concentration of dissolved oxygen in their waters ($R=0.51$, $p<0.001$), and also a higher amount of suspended soils ($R=-0.57$, $p<0.001$, Fig. 2 & 3). There

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[1] The 2009 NRMI is a standardized proximity-to-target score ranging from 0 to 100 for each of four measures; access to adequate sanitation, access to improved water, child mortality and eco-region protection. For Access to Adequate Sanitation and Access to Improved Water, the proximity-to-target measure is equal to the reported percentage. For example, if a country has 84% of its population with access to adequate sanitation, it is considered to have a proximity-to-target score of 84 out of 100. For child mortality, the ratio of the measured probability of dying is computed to the highest observed probability of dying, which is 0.141, and multiply that by 100 to make it comparable to the 0-100 scale used in the other measures. The proximity-to-target measure is this number, which ranges from 0-100, subtracted from 100. For example, a country whose children in the 1-5 age group have a probability of dying of 0.004 would have a proximity-to-target score of 97.2 (0.004/0.1414=0.028; 0.028 x100=2.8; 100-2.8=97.2). For eco-region protection the proximity-to-target score is 10 times the weighted average of the biome protection scores, which are capped at 10% to correspond to the target. For example, a country with 7% of its ecoregion's protected areas would have a proximity-to-target score of 70. The 10% target was established by the Convention on Biological Diversity (CBD) in decision VII/30 as target 1.1 of the 2010 Targets, "At least 10% of each of the world's ecological regions effectively conserved". The NRMI is the simple average of these four proximity-to-target scores. If a country is missing the child mortality or ecoregion protection data points, an NRMI is not calculated for it. If a country has one of the water and sanitation data points, but not the other, an NRMI is calculated on the basis of the one score (http://sedac.ciesin.columbia.edu/gateway/guides/nrmi_2009.html).

[2] The Corruption Perceptions Index (CPI) measures the perceived level of public-sector corruption in 180 countries and territories around the world. The CPI is a "survey of surveys", based on 13 different expert and business surveys (http://www.transparency.org/policy_research/surveys_indices/cpi/2009).

is also a correlation between available water and corruption with more corrupt countries also facing a higher degree of water stress (R=0.58, p<0.001Fig 4). The relationship looks very similar to the relationship between CPI and NRMI, reflecting that water availability is likely an important factor in resource management and that there is a high degree of correlation between variables in composite indices. However we found no correlation between flow regulation and corruption.

Table 1. Indices included in the correlation anlaysis.

Index
Ecological
Ecological risk
Percentage threatened birds
Percentage threatened mammals
Percentage threatened amphibians
National Biodiversity Index
Protected area
Biodiversity hotspot area (km^2)
Water quality and water stress
Water Quality Dissolved oxygen
Water Quality Electric conductivity
Water quality Phosphorous concentration
Water quality Suspended soils
Industrial organic water pollutant (BOD)
% of country under severe water stress
Flow alteration
Pressures
% change population 2004-2050
% undernourished in population
% of population access to clean water
Fertilizer consumption (per arable ha)
Salinized area due to irrigation
Carbon emission per capita
Hydropower and renewable energy production as % of total energy production
Socio-political indexes
Corruption measure
Rule of law
Civil and political liberties
Government efficiency
Democracy measure
Failed states index (FI 2009)
Corruption Perceptions Index (CPI 2009)
Environmental management
Environmental hazard disposure index
% variables missing from "Rio to Joburg" dashboard
Local AGENDA21 initiatives per million people
Number of memberships in environmental organizations
Participation in international environment agreements
Natural resource management index (NMRI)
IUCN member organizations per million people
Knowledge creation in environmental science, technology and policy

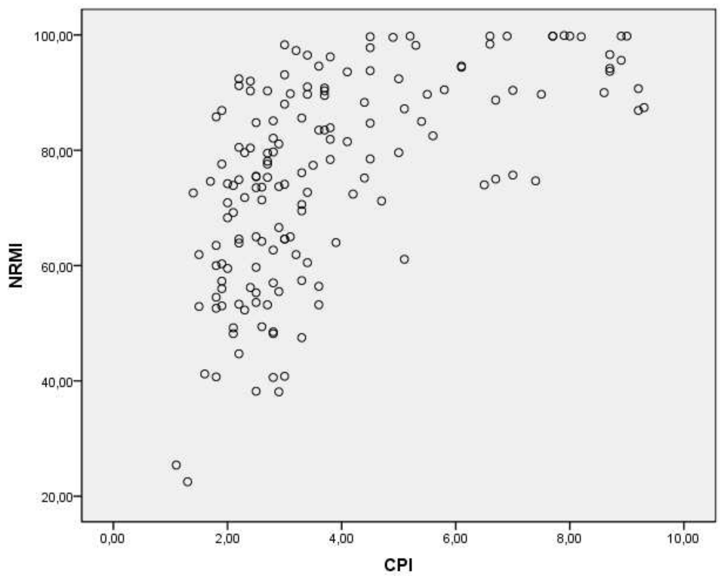

Figure1. We found a significant negative correlation (R= 0.59, p<0.001) between the Natural Resource Management Index (NMRI) and the Corruption Perception Index (CPI).

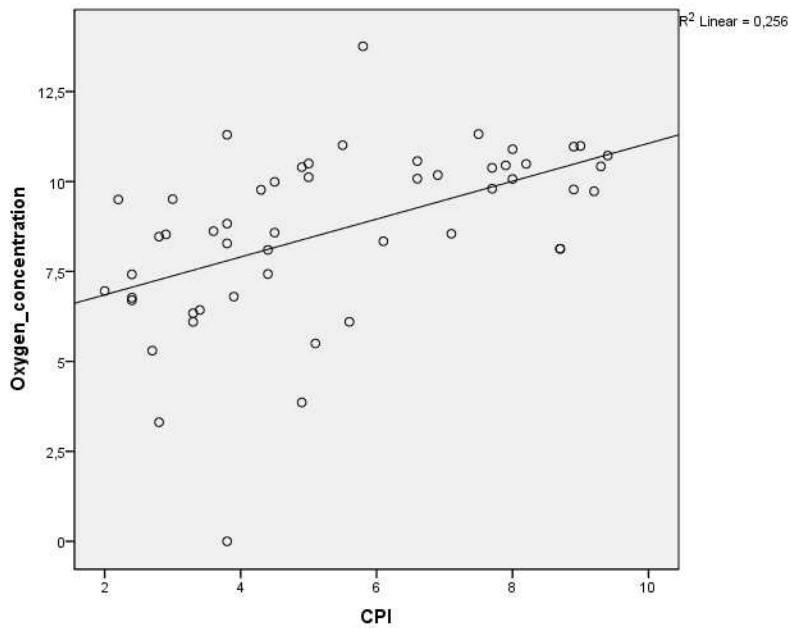

Figure2. We found a significant correlation (R=0.51, p<0.001) between dissolved oxygen concentration and the Corruption Perception Index (CPI) with more corrupt countries having a lower concentration of dissolved oxygen in their waters

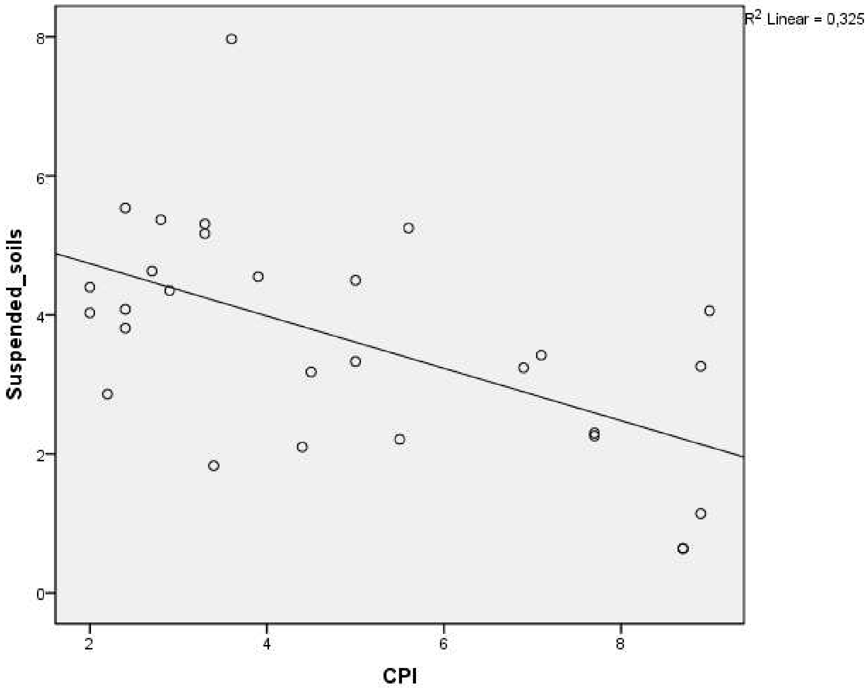

Figure 3. We found a significant correlation (R=-0.57, p<0.001) between concentration of suspended soil and the Corruption Perception Index (CPI) with more corrupt countries having a higher concentration of suspended soil in their waters.

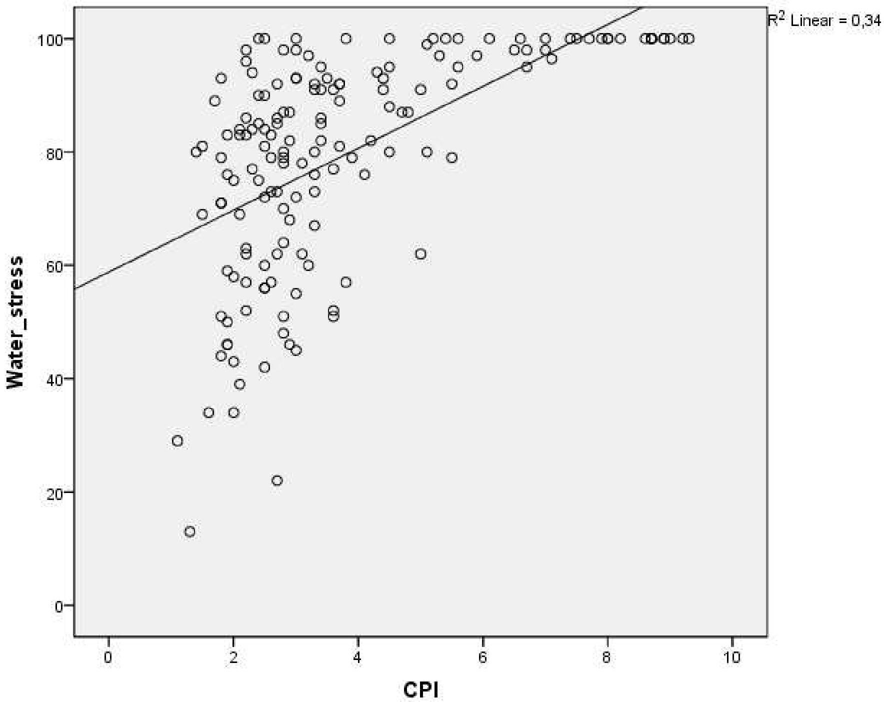

Figure 4. We found a significant correlation (R=0.58, p<0.001) between water stress (% of population access to clean water) and the Corruption Perception Index (CPI) with more corrupt countries having a lower accessibility to water.

There is a correlation between the National Biodiversity Index (NBI[3]) and countries that are perceived as being more corrupt also have a higher biodiversity (R=-0.33, p<0.001, Fig 5). Given the negative relationship between corruption and management of natural resources, increasing economic development without coming to terms with corruption, is likely to pose a great threat to existing biodiversity.

There is also a significant relationship between population growth and CPI, with a higher growth in more corrupt countries (R=-0.47, p<0.001,Fig 6). This will increase pressure on the aquatic environment as more water will be required for food production. Without good environmental management it is also likely the water quality problems will increase. We found no significant correlation between National Biodiversity Index and population growth. It seems though, that the highest growth will take place in areas of intermediate richness (Fig 7). The NBI is also correlated to water quality, with deteriorating water quality in areas of higher biodiversity (Fig 8 & 9).

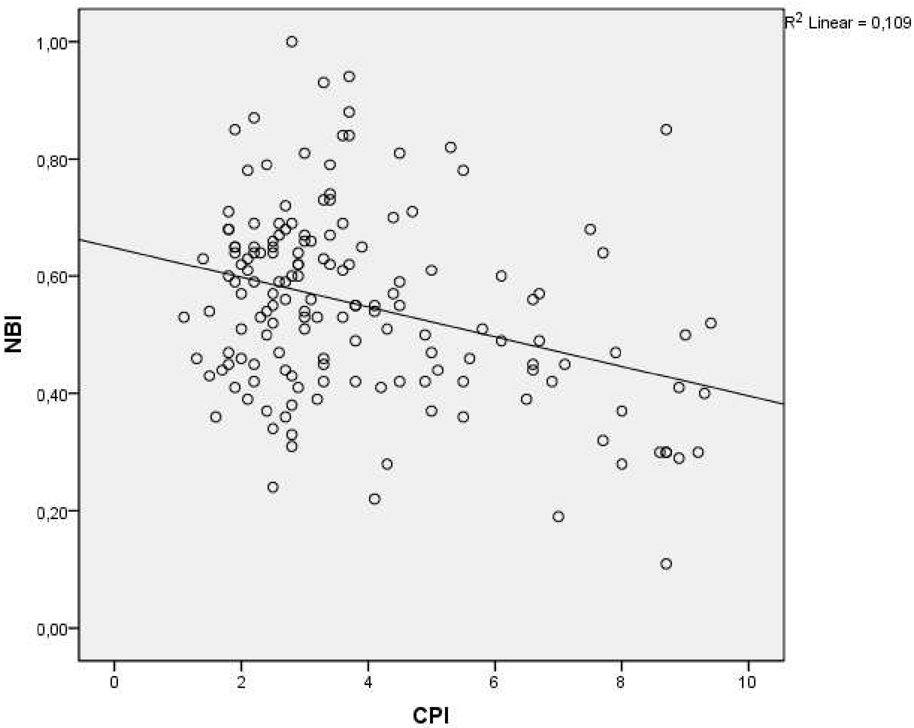

Figure 5. There is a correlation (R=-0.33, p<0.001) between the National Biodiversity Index (NBI) and countries that are perceived as being more corrupt, with more corrupt countries having a higher biodiversity.

[3] National Biodiversity Index. This index is based on estimates of country richness and endemism in four terrestrial vertebrate classes and vascular plants; vertebrates and plants are ranked equally; index values range between 1.000 (maximum: Indonesia) and 0.000 (minimum: Greenland, not shown in table). The NBI includes some adjustment allowing for country size. Countries with land area less than 5,000 sq km are excluded. Overseas territories and dependencies are excluded. (http://www.cbd.int/gbo1/annex.shtml)

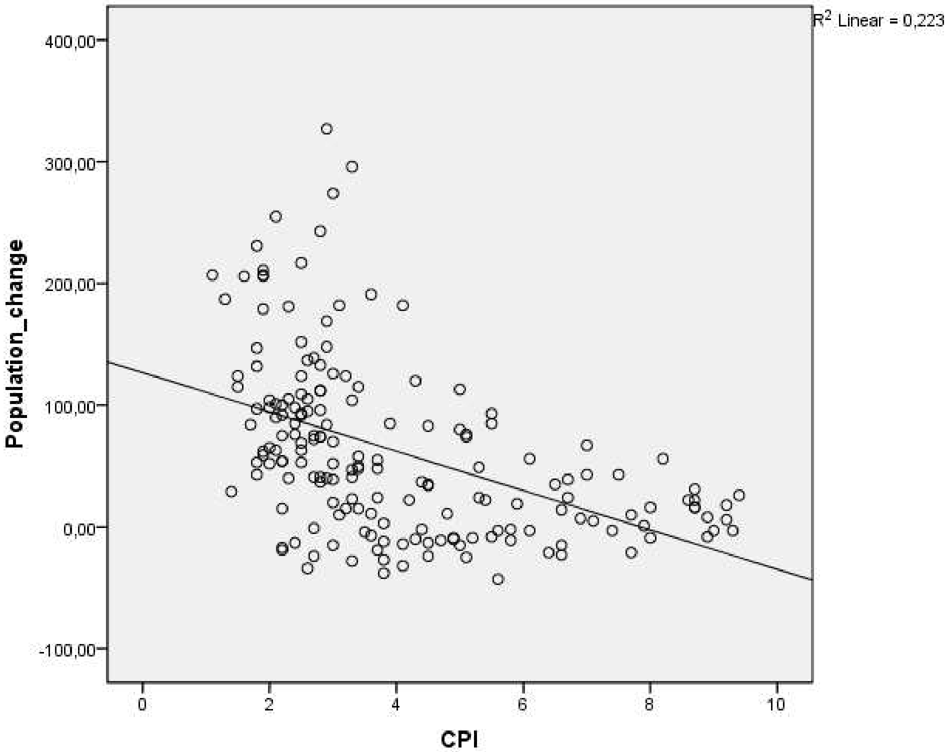

Figure 6. There is a significant correlation (R=-0.47, p<0.001) between the population growth (% change population 2004-2050) and CPI, with countries that are perceived as being more corrupt also have a higher forecasted population increase.

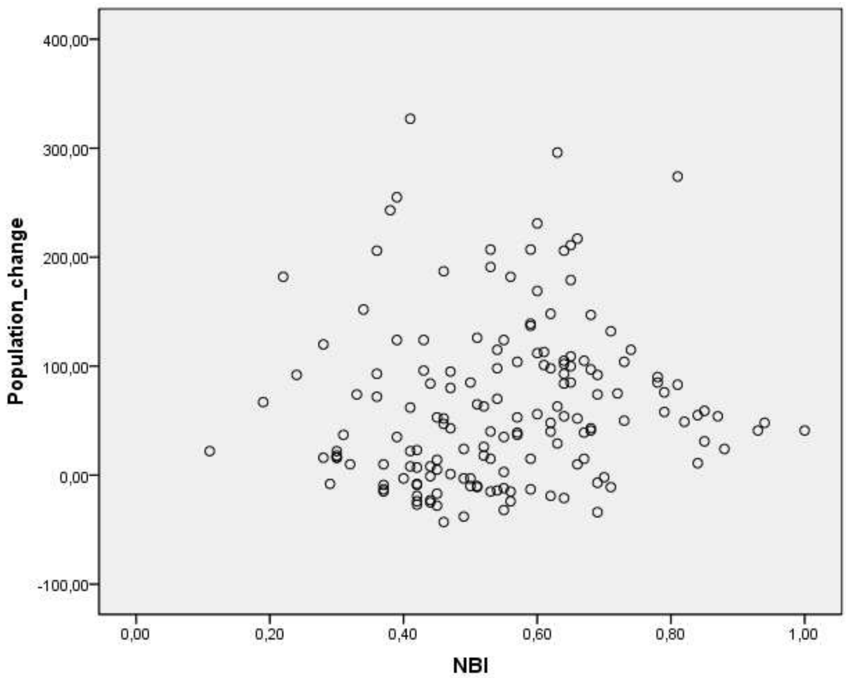

Figure 7. There is no significant correlation between the National Biodiversity Index (NBI) and population change. Countries where highest growth is forecasted have intermediate biodiversity.

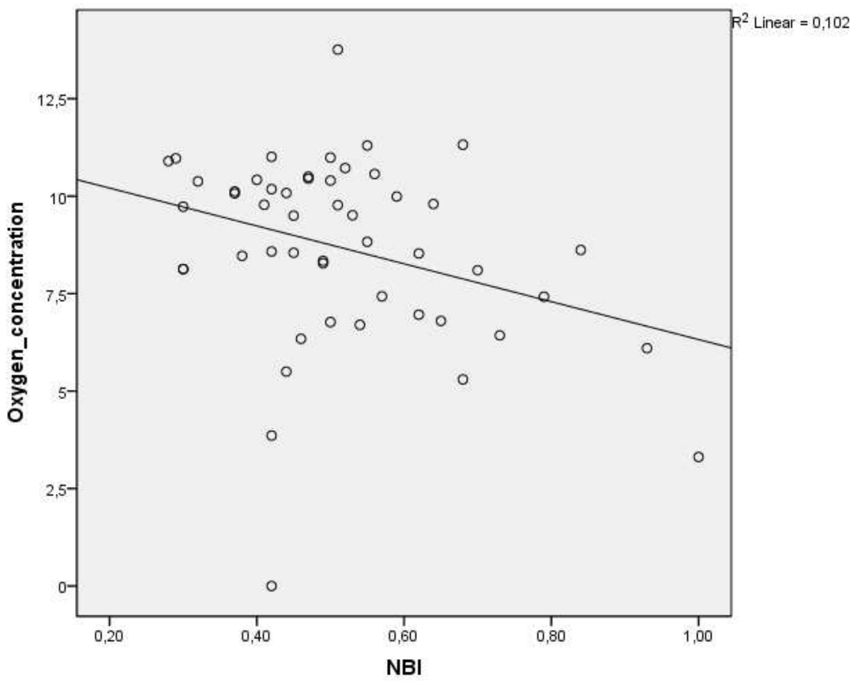

Figure 8. There is a significant correlation (R=-0.32, p=0.23) between NBI and dissolved oxygen concentration.

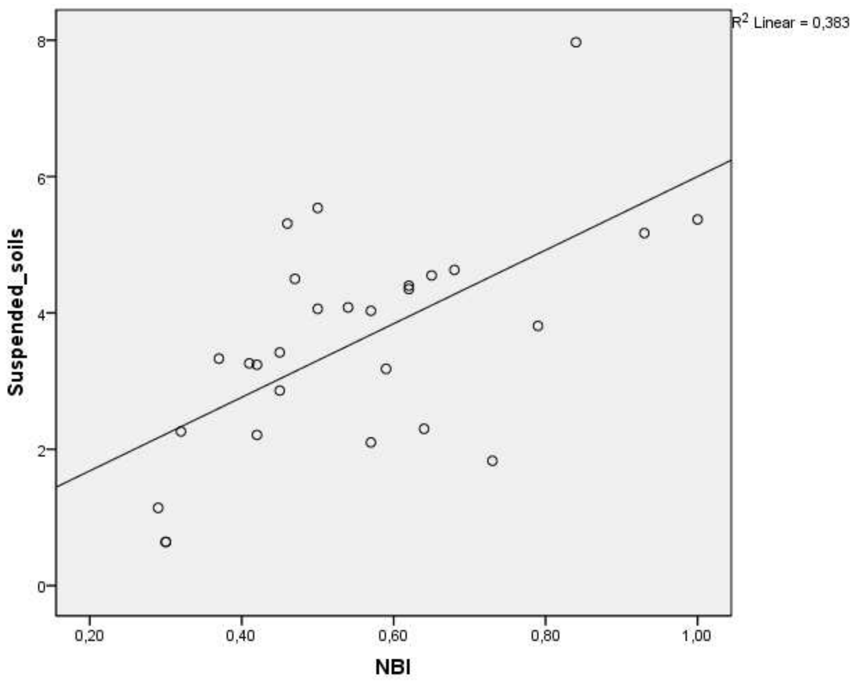

Figure 9. There is a significant correlation (R=0.62, p=0.23) between NBI and suspended soil concentration.

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Long-list: Future themes in water management in the context of global change

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Milestone Report

for the project

Analysis of potentially new themes in
water management - future trends and research needs
(Analyse zu potentiellen neuen Themenfeldern im Wasserbereich
- Forschungstrends und Forschungsbedarf)

GEFÖRDERT VOM

Institut für Umweltsystemforschung Universität Osnabrück

Bundesministerium für Bildung und Forschung

Osnabrück, 22.12.2009

This long-list of future water management themes in the context of global change is an intermediary working report for the purpose of informing the BMBF and the DLR about the progress of the project. The report makes no claim to be complete. Further input for the in depth analysis will be provided by a workshop in February 2010 as well as in the second period of the project (Jan 2010 – June 2010).

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Content

Figures and Tables

1 Introduction

Water resources management has become an important theme on the scientific and political agendas. The importance of the international dimension and impacts of global change have moved in the centre of attention. Numerous national and international programs have addressed water related themes. The German Ministry of Education and Research (BMBF) has funded several major research programs on Integrated Water Resources Management and Global Change. The goal of this study is to make recommendations for promising future research themes by analysing the international water research and policy landscape and by taking stock of recent achievements. The study has thus the following objectives:

- Provide an overview of recent and emerging developments in topical research areas in the field of water resources of high scientific and political relevance.
- Evaluate research themes with respect to their potential for scientific breakthroughs, political impact and suitability for the German water community.
- Develop recommendations for a future research programme of the BMBF.

The sustainable management of water resources in times of global change is one of the most pressing challenges of the 21st century. Globally freshwater resources are not (yet) scarce but they are unequally distributed among world regions, but also among countries and different social groups within a river basin. The urgency of the problem is reflected in some figures on key water and sanitation statistics published by the UN programme on Water for Life[1]:

- The world's population, 6.2 billion people in 2002, is expected to increase to approximately 7.2 billion people by 2015. Almost 95 per cent of the increase is expected to be in developing regions.
- Water withdrawals for irrigation have increased by over 60 per cent since 1960. About 70 per cent of all available freshwater is used for irrigation in agriculture. Yet because of inefficient irrigation systems, particularly in developing countries, 60 per cent of this water is lost to evaporation or is returned to rivers and groundwater aquifers.
- Water use increased six-fold during the 20th Century, more than twice the rate of population growth. While water consumption in industrialized countries runs as high as 380 litres/capita/day in the United States and 129 litres/capita/day in Germany, in developing countries 20-30 litres/capita/day are considered enough to meet basic human needs.
- In parts of the United States, China and India, groundwater is being consumed faster than it is being replenished, and groundwater tables are steadily falling. Some rivers, such as the Colorado River in the western United States and the Yellow River in China, often run dry before they reach the sea.
- Freshwater ecosystems have been severely degraded: it is estimated that about half the world's wetlands have been lost, and more than 20 per cent of the world's 10,000 known freshwater species have become extinct, threatened or endangered.

This dire situation is aggravated by the potential impacts of climate change which may even intensify some problems and which introduces another dimension of major uncertainty into the development of sustainable water management regimes.

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[1] http://www.un.org/waterforlifedecade/factsheet.html

Another important aspect is the increasing awareness that water is a global issue. Water problems have traditionally been considered to be local or regional problems. However, there are strong arguments to take the global dimension into account (Pahl-Wostl, et al. 2008; Alcamo et al. 2008). First, the hydrological system is a global system and exchange processes occur at global level over relevant time periods (e.g. climate change impacts; other teleconnections for instance between deforestation and precipitation). Second, global environmental change (GEC) and socio-economic phenomena at the global level increasingly create situations in which the driving forces behind water related problems and conflicts lie outside the reach of local, national or basin oriented governance regimes (e.g. global trade impacts on water quantity and quality). Third, many local phenomena occur globally such as erosion, eutrophication, urbanisation, biodiversity loss, or the introduction of invasive species. The same is valid for many human health issues like the poor quality of drinking water supply and of sanitation in poor countries. Such local phenomena may imply alarming global trends, e.g. the construction of dams led to a fragmentation and flow alteration of the world's river basins with major and sometimes irreversible impacts on associated freshwater ecosystems (Nilsson et al. 2005). Furthermore, lessons learnt in one part of the world, could be useful and relevant for other parts of the world and comparative learning justifies a global approach.

Unfortunately dealing with water issues was often linked to technological or institutional panaceas. What is needed is an approach which develops tools to analyse problems embedded in context and supports the development of context specific integrated solution instead of advocating simplistic panaceas.

Based on a preliminary assessment the following six cluster themes of high political relevance and major research needs have been identified:

1. Adaptation to climate change
2. Food and water – virtual water flows
3. Urbanization and infrastructure
4. Disasters and vulnerability to water related threats
5. Water governance (cross-cutting)
6. Ecosystem water requirements – environmental flows (cross-cutting)

With respect to the core themes above, this report presents an evaluated long-list of the most important future themes in water research. The long-list builds upon a detailed literature screening regarding the recent and emerging developments in topical research areas in the field of water resources and an evaluation of the research themes regarding their potential for scientific breakthroughs and political impact. Criteria of the evaluation were:

- Gaps in scientific knowledge and potential to achieve scientific breakthroughs
- Relevance of international policy problem
- Suitability of the program to be implemented in the German scientific community (critical stock of available expertise, potential to strengthen an emerging research community)
- Science-policy interplay - link to relevant stakeholders, efficiency and effectiveness of implementation, potential of a programme to have a real impact

This long-list is the starting point for the in depth analysis, which will take place from January until June 2010. Further input for the in depth analysis will be provided by a workshop which will be conducted in February 2010 in Osnabrück. About 20 national and international experts of water research and management will be invited in order to discuss the long-list, cluster the different topics of the list and give recommendations for the further focus of the study. Particularly the last two evaluation criteria will be further investigated also after the workshop in consultation of leading German water management experts.

2 Overview of future themes in water management

2.1 Adaptation to climate change

(Authors: Claudia Pahl-Wostl, Patrick Huntjens, Nick van de Giesen)

2.1.1 Natural science perspective

Drivers: General Circulation Models (GCM's) and water

The single most physical science question with respect to water and climate change is the representation of the hydrological cycle in General Circulation Models. GCM's have been developed to reproduce and predict changes in atmospheric temperature. Unfortunately, GCM's are extremely poor where it comes to the hydrological cycle. This is not unknown and the reports that present GCM's do contain appropriate error bars. Such errors are, however, usually in the order of one to two millimetres per day. This may not sound like much but such errors basically imply that we do not know anything; Germany may in the future receive as little rain as a desert or as much as a rainforest. It is understandable that a temperature model does not do water well in the same way that hydrological models normally do not "care" about temperatures. Given the links between the hydrological and energy cycles and, more indirectly, the hydrological and carbon cycles, one would like to improve the accuracy with which the hydrological cycle is represented in GCM's. Over the past decades, however, we have not witnessed any significant improvements. An explicit call for such improvements seems necessary if we ever want to predict with any confidence what societal impacts climate change will have.

Moreover, a somewhat stronger form of downscaling is more physically based and consists of more detailed climate simulations within large windows over a region of interest. In such case, the (changed) boundary conditions are provided by the GCM's, giving (changes in) large scale circulation patterns. Within the window, a more detailed atmospheric model provides the effects of changes in large scale circulation on regional weather patterns. There are two important conceptual problems with this approach. First, the region of interest is likely to also have an effect on the circulation patterns surrounding it. Second, certain aspects of the boundary conditions, such as the convergence of atmospheric moisture and all their error, will be carried over into the smaller domains. Because moisture convergence equals river flow over larger periods, such errors would have important consequences for water resource projections. One may, therefore, also produce nested windows in which each next smaller window zooms in on the region of interest, thereby minimizing the impact of errors in boundary conditions. The extent to which such zooming-in really removes the errors remains unknown. In either case, the effect that the region has on its surroundings remains unclear. If we would also like to take into account the effect of, say, changes in landuse, we simply need to develop better models at global level.

Drivers: Direct impact through changes in temperature

Probably the better understood impacts of climate change on the hydrological cycle are those induced directly through increases in air temperature. For example, the rise in the snowline in the Alps will lead to changes in discharge regimes in the Rhine. From a mixed snow-melt/rainfall river, the Rhine will change into a rainfall river with less flow in summer. However, even the reduction of glaciers is not a given everywhere as increased air temperature may lead to increased moisture transport from sea to (ant)arctic glaciers, such as observed in Norway. This leads to an interesting general science question, namely the acceleration of the hydrological cycle as a function of air temperature. Our statistics are not yet clear enough but it is interesting to note that until about four years ago, there seemed to be a consensus that per degree temperature rise, the hydrological cycle would accelerate with 2% - 4%. A heuristic argument, based on the Clausius-Clapeyron equation, could be made that per degree, the hydrological cycle would accelerate with 7% because the water holding capacity of air at the present average air temperature increases with 7%/K. Air flowing over the ocean would, therefore, pick up 7% more water to transport to the continents. The argument for a lower percentage was that there would be negative feedbacks that would reduce the percentage. In 2007, Wentz et al. showed that over oceans at least, measured rainfall increased indeed with 7%/K. In 2009, Liu et al., bring forward data that suggest a positive feedback and an increase of 23%/K over land. A relevant science question then becomes what the ratio is between acceleration of the hydrological cycle and a rise in air temperature. Although answering this question still falls far short of the detailed information needed for regional water resources planning, we would start to gain important general insights and constraints on GCM projections.

Drivers: Indirect impacts through changes in circulation patterns

Investments in water resources infrastructure, such as sewage systems, drainage works, irrigation schemes, dams and reservoirs, dikes and sluices, typically have a long life span of >50 years. Such investments amount globally to hundreds of billions of Euros per year. Even a small percentage of these investments would pay for better information of the likely impact that climate change will have on regional water resources availability. These impacts will mainly be caused by relatively subtle changes in regional circulation patterns. It is, therefore, imperative to obtain a better handle on these circulation patterns. So far, however, we do not have enough statistical information or good enough models to say in any relevant detail what regional changes in the hydrological cycle are likely to occur. One should realize that especially extremes are of interest here. Even the proper statistical characteristics of present climate extremes is difficult for the simple reason that one needs long time series to estimate higher moments of statistical distributions. Changes in such higher moments are even more difficult to detect with any statistical significance. Better tools to deal with non-stationary time series would be a simple way, or at least a shortcut towards, regional hydrological assessment of climate change impact. Eventually, fully coupled atmosphere, ocean, landsurface models will be needed to accurately assess the impact of climate change on water resources. Presently, GCM's mainly take atmosphere and ocean into account under the argument that these two elements determine to a large extent our present climate. This may be true but we tend to live on the continents and land feedback has been shown to be very relevant for water resources such as during the European 2003 drought and, in general, the Sahelian drought.

Before we can come to a completely coupled model, a global hydrological model would be an important first step. Such a model is feasible from a computational point of view but difficult from a parametric point of view. In contrast to ocean and atmosphere models, the terrestrial branch of the hydrological cycle is to a large extent determined by processes that can only parameterized through so called "effective parameters". Although we do understand the flow of water through a small soil core, we can not measure all soil pores at the landscape level. Instead, we have to determine "effective parameters" that enter simplified water flow models. For a global model, we need to determine these parameters. Such parameters can only be obtained through some form of calibration.

For a globally calibrated model, we need a better land-based observation network. There are plenty opportunities in the near future with readily available technologies to build such a network, and this would be an important short-term scientific goal. In addition, better use needs to be made of satellite data that provide consistent information at global level. Mathematically, we need better data assimilation methods that link models and observations in an optimal way. Finally, it is unlikely, and perhaps unwanted, to have one monolithic model for the whole globe. Instead, a more wiki-based approach in which stakeholders and local water managers fill the voids in a first order global model may be the better way forward.

Impact: Global water use model

Although a global hydrological model poses a large number of challenges, an even more difficult accompanying global water use model would be needed as well. Fortunately, it may be easier to add detail to such models over time as information becomes available. There are already a number of global water use models and Germany has a strong representation in this modeling community. Especially questions concerning food production, the role of virtual water trade, water quality issues, and water available to maintain ecological functions of streams, rivers, and lakes can be answered through improved global water use models. The intrinsic knowledge is generally available. A move from a few "competing" models to an open community based model structure may be a way forward.

Mitigation: Food – energy – water nexus

Water and climate questions are generally framed in terms of impact; water is the passive outcome of the global change process. To some extent, water is also part of the mitigation question. This holds especially true for questions surrounding the so called food-energy-water nexus.

There are many points at which the water and energy (production) cycles touch. There are first order contacts, for example in the generation of hydropower. Within the European context, also second order contact points, such as the reduced availability of cooling water for thermal power plants in summer time, may be relevant. Water also offers some true mitigation opportunities in the sense that it is a good storage medium of heat and "cold". Especially in the West European urban setting, water may play an important role in preventing cities to massively turn to air conditioning. A comprehensive assessment of water as coolant and carrier of energy would reveal our vulnerabilities and opportunities with respect to the connections between water and energy.

The combined analysis of water-food-energy is also a field largely untouched by science. So far, food production is usually perceived as being the product of independent production factors while there are clear dependencies at plant, field, and system levels between water, energy, and food. At plant level, one should asses the combined effects that water and nutrient availability have on root growth and plant development. The production of nitrogen fertilizer is very energy intensive and when fertilizer use can be reduced through better water management, this would have a significant impact on our carbon footprint. At field and system level, one should take into account the energy needs of different water application schemes. In much of South, East and South-East Asia, water use efficiencies at field level are not taken seriously because at system level this is compensated by pumping up shallow groundwater. From an energy perspective, however, this is sub-optimal and subject to substantial improvement.

Finally, there is the rise of bio-based fuels and industrial raw materials. For the next five to ten years, the competition for water induced by the increased demand for biofuels will be limited to some regions or provinces within China and Brazil. If, however, in the longer term, biofuels are seen as a viable alternative to fossil fuels, and if the so-called third generation biofuel technology is not developed in time, the competition for water resources may significantly be exacerbated. Under present production relations, the water footprint of a person living in a developed country would double when their transportation needs would have to be covered through biofuels. At the same time, more localized and advanced use of energy in agricultural waste would greatly contribute to climate change mitigation.

Adaptation: Role of technology

The possible role of technology in adaptation to climate change is most likely very much under appreciated. The dynamics behind this under-appreciation are clear because we do not want to be "techno optimists" or take the stance that it all does not matter because technology will solve all problems. Still, it would make sense to have a realistic assessment of which problems can be taken care off and which ones we simply have to adapt to in a more passive way.

The interaction between physical and social sciences is most prominent in this area. One may, for example, argue that reduced snow packs in the Alps may be compensated by increased (hydropower) storage in Switzerland. Within the Swiss political context, however, it is clear that it is not likely that a significant amount of extra reservoir storage will be created within the next generation. Instead of trying to model what technologies are most likely to evolve in the face of climate change, it makes more sense to treat technology as a constraint in an optimization exercise. The question then becomes where investments have to be made to have the most significant impact. It should also be recognized that, if the past 50 years are predictive for the next 50 years, the number of quantum leaps in water resources management will be very limited. Water productivity in terms of food production has clear physiological limits and we will "always" need at least 500 kg of water for every kilogram of food produced. Floods will be coped with by the construction of dikes and reservoirs. Only the software, or the optimal control, of existing technology is still something that may lead to increased efficiencies and is worthy of intensified research. The only sector in which we can continue to expect major technological improvements is in water quality management. The increased value that societies put on proper ecological functioning of water bodies and water derived ecosystems clearly allows for extra investments in recycling of water, improved cleaning of process water, etc.

Adaptation: Optimal global water use

Perhaps not the main focus of future research but worth a mention is the global optimization of water use. When there will indeed be water wars and a crush on water resources, it would make sense to step back and assess where what water should be used for what. It is very tempting to irrigate in the desert as agricultural productivity in these settings is very high. We have, however, examples of this strategy going awry due to ecological reasons (Central Asia / Aral Sea) or to underestimated climatic variability (Australia). Especially the role of virtual water trade becomes interesting from a global perspective. Without any normative pretension, a global water use optimization vision would have value. Where does one invest in irrigation? To what extent does it make sense to strive towards food self sufficiency? What are the ecological and economic costs of politically desirable but otherwise sub-optimal water resources development strategies? Do large scale inter-basin water transfers such as the South-to-North carrier in China, the major transfers foreseen in India, or even the transfer of water-rich Canada to the water-hungry mid-West of the United States, make sense? Such a global study would provide important long-term insight into what would be rational governance of water resources worldwide.

2.1.2 Social science perspective

Based on a literature review combined with the input from 14 leading experts working in this field some general tendencies can be observed as regards current and future research trends in climate change adaptation from a water governance perspective. One general pattern being observed is that research efforts seem to concentrate on five institutional dimensions of climate change adaptation:

1) **Multi-perspective**: focusing on problem framing, discourses and possibilities for reorientation;
2) **Multi-level**: focusing on scale, governance levels, development of the public domain (e.g. property rights) and possibilities for changing the institutional setting;
3) **Multi-actor**: focusing on the complexity of actor networks in public governance, fragmentation, transitions towards integration, possibilities for transition and using complexity and social dynamics for realizing this;
4) **Multi-strategy**: fine-tuning a balance between top-down and bottom-up approaches and related governance issues, and possibilities for re-adjustment of these processes;
5) **Multi-resource**: focusing on top-down and bottom-up processes and resources (economic, human and organizational) which need to be mobilized for strategy development, implementation and possibilities for strengthening the governance capacity to implement.

A collective effort to synthesize the findings with respect to climate change adaptation by Burton et al (2007) generated a common list of nine lessons: 1) Adapt now!; 2) create the necessary conditions to enable adaptation; 3) integrated adaptation with development; 4) increase awareness and knowledge; 5) strengthen institutions; 6) protect natural resources; 7) provide financial assistance; 8) involve those at risk; use place-specific strategies. Notwithstanding the previous eight conclusions, adaptation needs to be based on recognition of the individual circumstances of each place.

In concrete, important social science future research themes in the context of adaptation to climate change are:

Assessing the inherent characteristics of institutions to stimulate the adaptive capacity of society to respond to (the impacts of) climate change; and to focus on whether and how institutions need to be redesigned.

Rather than trying to search for the single set of rules that is the optimal set for every type of problem, it is important to focus on the underlying designs of those real-world experiments that have proved to be robust over time. This topic has received a lot of attention lately, amongst others since Prof. Elinor Ostrom has won the 2009 Nobel Prize in Economics for her analysis of economic governance; showing how common property can be successfully managed by groups using it. Her work is relevant to many fields, including the institutional analysis of environmental challenges in water resources management; challenges which are being aggravated by climate change impacts. Many researchers have been using Ostrom's work (Ostrom 1990, 1995, 2005) for analyzing institutions on a local scale, and more recently also on a regional scale with a specific focus on climate change adaptation (Huntjens, et al., 2009). Important open questions refer to the assessment of the capacity of institutions to adapt to climate change and the way in which institutional arrangements can enhance that capacity. Moreover, to gain an understanding of the underlying processes of climate change adaptation as regards trust building, conflict resolution and pursuits of social justice among parties differentially vulnerable to floods or droughts, and the way in which (i) these processes, (ii) the substance of adaptation processes and (iii) institutional design principles affect each other has so far not been explored in detail.

Understanding of adaptation strategies as multilevel governance processes and cross-scale interactions

A key challenge for policy-makers is how best to integrate important 'bottom-up' processes of learning with 'top-down' high-level policy strategies and visions. It is clear that a 'one-size-fits-all' approach for adaptation is not appropriate for the complexities of climate change. Strategies should stimulate and support pro-active adaptation responses, whilst retaining the flexibility and robustness necessary for enabling the development, testing and implementation of measures at the local scale. The complexities of climate change adaptation poses a major challenge for strategic policy communities, since integration needs to occur horizontally across different sectors and policy areas. This ultimately will require the consideration of adaptation through existing institutional mechanisms, a process commonly known as 'mainstreaming'. The need for better understanding of cross-scale interactions in natural resource governance is put forward by many scholars (e.g. Berkes, 2008; Cash et al., 2006; Ostrom, 2005). Such cross-scale interactions also affect how social networks influence governance processes. It could therefore be of great value in researching natural resource governance processes ranging from the local to the global thus enabling understanding of various factors driving global environmental change.

How to ensure the integrity, accountability and legitimacy of governance for climate change adaptation?

Integrity and accountability are critical to good governance of water resources and services (UNDP Water Governance Facility, 2009). Ensuring the accountability and legitimacy of governance is an important field for research in climate change adaptation, as it is for related governance fields, such as disaster risk reduction, poverty reduction and sustainable development. The more regulatory competence and authority is conferred upon larger institutions and systems of governance - especially at the global level - the more we will be confronted with questions of how to ensure the accountability and legitimacy of governance (Biermann, et al. 2009). Simply put, we are faced with the need to understand the democratic quality of water governance. What are the sources of accountability and legitimacy in water governance? What are the effects of different forms and degrees of accountability and legitimacy for the performance of governance systems? What institutional designs (e.g. for achieving more transparency or less corruption) can produce the accountability and legitimacy of earth system governance in a way that guarantees balances of interests and perspectives?

What strategies and governance arrangements are needed in water management to take into account not only existing uncertainties but also the possibility that some uncertainties about future conditions may expand as climate change progresses?

When adaptation to flood situations is necessary it is relatively easy to adapt the tools for disaster reduction management to also deal with future climate situations. There is however one serious issue: uncertainty. When 'normal' floods can be treated as a statistical phenomenon, under climate change conditions the past is no longer the predictor for the future. This increased uncertainty is a characteristic of the whole area of climate change research and policy. Thus, the overall question mentioned above should be combined with developing methods for dealing with uncertainties in decision-making (e.g. long term scenario analyses, risk assessments, vulnerability assessments). A first step to deal with it always includes a scenario analysis leading to 'possible futures', not 'probable futures' as in statistical analysis. These scenarios have to be downscaled to the level of the system that has to be adapted to climate change. For climate change and water in Europe e.g. this is done in a project called SCENES.[2] Both steps, the scenarios and the downscaling, introduce large uncertainties. There is no way to make these disappear: they have to be dealt with. Hence, developing methods for dealing with uncertainties in decision-making (e.g. long terms scenario analyses, risk assessments, vulnerability assessments) are regarded as a key research area at various research institutes in Europe,[3] but also outside Europe, notably in the United States and Australia.

What are appropriate economic instruments for climate change adaptation (e.g. insurance, water pricing, public-private partnerships), taking into account environmental justice and equity?

Perhaps the best way to utilize water to the best and most-valued uses is to put a price on water, and construct appropriate tariff structures to meet different social, political and economic goals in different situations. It has been argued that price policy can help maintain the sustainability of the resource itself: when the price of water reflects its true cost, the resource will be put to its most valuable uses (Rogers et al., 2002). Thereby, and assuming the poor can pay for such services, water pricing could contribute to adaptation and, for instance, if resources become scarce and water use is stabilized or reduced. Furthermore, if water resources are managed in an integrated fashion where the economic, legal and environmental aspects complement each other, increased prices can improve equity, efficiency and sustainability of the resource. Thus in the future, water pricing mechanisms can be used to send a scarcity signal and help balance supply and demand.

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[2] see e.g. http://library.wur.nl/WebQuery/wurpubs/lang/375287)

[3] For example at the Copernicus Institute, Jeroen van der Sluijs et al. have developed tools to deal with uncertainty in decision making (http://www.geo.uu.nl/20419main.html)

The potential for new patterns of extreme events resulting from climate change will likely increase demand for insurance while challenging the industry's ability to assume new risks (Mills, 2007). The engagement of the private sector that calculates risk, such as the insurance sector, could provide opportunities to gain insight into risks, and ways to either transfer or reduce risks. Moreover, innovative insurance products, such as catastrophe bonds and weather index insurance systems (e.g. providing payments during drought) can play a viable role if tied to efforts aimed at vulnerability reduction (Bakker & Van Schaik, 2008). However, climate change promises to erode the insurability of many risks, and insurance responses can be more reactive than proactive, resulting in compromised insurance affordability and/or availability.

One of the main challenges of water governments is: how to finance climate change adaptation plans, operations, infrastructure and projects? The last few decennia new forms of finance scheme and structures have become available and are now commonly used. These modern forms, finance schedules and structures are often known as public-private partnerships (or PPP's). Within the context of climate change adaptation PPP's might enable the public sector to spread the cost of the investment over the lifetime, in contrast to traditional financing where the public sector is required to provide capital, while the benefits will come much later and are mostly uncertain.

How to measure vulnerability (over time and space) and how to characterize resilience and adaptive capacity in multifunctional landscapes?

Especially in developing countries poverty and vulnerability to disasters are closely linked. (Brauch et al., 2008) The poor are disproportionately affected by disasters (GFDRR, 2008), due to their lack of assets with which to smooth consumption and respond to catastrophic events. Moreover, the poor are forced to accept a higher exposure to hazards. Typically, they live in unsafe areas on marginal lands such as flood plains, slopes of steep hillsides, and river beds. With urbanization, and agricultural modernization, more and more economic activities are taking place in seasonally flooded plains, putting more people and infrastructure at risk (Lebel & Sinh, 2007). It is expected that this exposure will increase. Programs and policies to minimize natural catastrophic losses, to improve public and private responses, and to institute appropriate risk transfer mechanisms will have a high anti-poverty impact (GFDRR, 2008; Lebel & Sinh, forthcoming, 2009).

2.2 Food and water – virtual water flows

(Authors: Peter Droogers, Nick van de Giesen)

Trends in food demand

Food production will have to increase by 1-2% per year for the next generation in order to keep up with food demand. Increase in food demand is caused by a combination of population growth and changes in consumption patterns, especially an increase in animal-based protein in our diets (Liu & Savenije, 2008). The production of biofuels may, until the advent of so-called third generation biofuels, put extra stress on grain and sugar production. The spike in food prices in 2008 (see Figure 1) has dampened but food prices are still 70% higher than they were five years ago. It has been known for a long time that the supply elasticity of food is low. World trade without dramatic productivity rises can, therefore, only be a limited solution.

There are many direct links between food production and water. In this report, we distinguish four areas:

1. Rainfed agriculture
2. Irrigated agriculture
3. Fresh water and fishery
4. Water and livestock

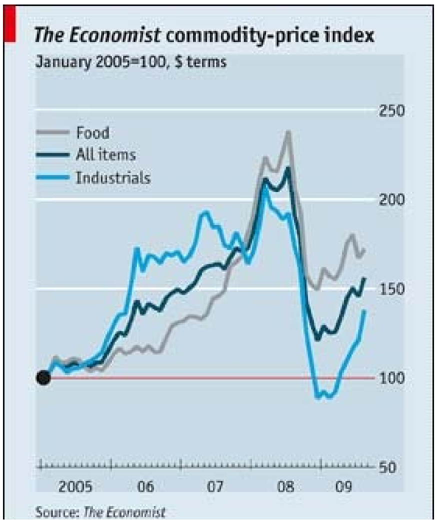

Figure 1: Commodity price development.

Global analysis of food production and its dependency on water

Various global assessment studies using an integrated approach to water and food exist. The approaches followed by these global studies can be divided into two groups. One the one hand exist studies that have a strong embedding in the economic science where physical (hydrological) processes are to a large extent ignored. In these studies water-food issues are represented by simplified parametric equations and the main driving forces are considered to be the economic ones. These economics are often driven by food demand and food supply.

One common weakness is the focus on average conditions. There are hardly any global studies that include the natural year-to-year variation in the analysis, while it is expected that the impact of climate change will alter not only the mean but will have a significant increase on extremes. There is need for a global model that maps future food productivity with sufficient realistic detail. The dependence on water for each production type needs to be analyzed.

Role of trade and virtual water

Richer countries have not been self-sufficient in their food supply for a very long time. Especially the poor in the world have suffered from recent food price increases. The possibility for densely populated poor countries to increase their food production is not a given. The question then becomes where the extra food needed can be grown and if trade can ensure delivery to those who need it most. The water needed to produce these commodities is called "virtual water" and many studies have been undertaken that map the virtual water content of goods and map global flows (Hoekstra & Chapagain, 2008). A global optimization of food production from a water perspective would be an important next step towards good water governance.

2.2.1 Rainfed agriculture

The most important research issues regarding Water and Rainfed Agriculture are:

Global opportunities rainfed agriculture

There is still a scientific debate on the potential of rainfed agriculture to feed the world in the future. Some research suggests that this potential is sufficient to feed the expected 9 billion world population while other studies indicate severe food shortages. These differences are often a reflection of different assumptions, often in terms of limiting factors in rainfed production, in the analysis. Research is therefore needed with a clear focus and appropriate definitions on these limitations. Analysis should therefore start with the full potential of rainfed agriculture, assuming no limitations at all. Stepwise, limitations would be added on this potential such as: water, land, investments, farmer knowledge, climate change etc.

Studies at the local scale

Research issues on water and rainfed agriculture are so-far mainly oriented towards arid and semi-arid areas with a focus on rainwater harvesting. There is a clear need for studies that will include the following four integrated components: (i) humid areas, (ii) expand the very local focus to more generic conclusions, (iii) impact of rainwater harvesting on downstream water users, and (iv)water productivity.

Yield gap

Closing the yield gap is seen as an important aspect to increase food production and reduce water consumption by crops. Two promising and unexplored research themes can be identified. First, yield gap research is in many cases very local, crop specific and more descriptive. There is a clear need to upgrade yield gap studies at a higher conceptual level based on fundamental deductive analyses. A second research need is yield gap analyses at larger scale levels (regions) with a strong emphasis on water issues including impact on other water users in the region.

CO_2 fertilization

It is clear that atmospheric CO_2 enrichment may stimulate plant growth directly through (1) enhanced photosynthesis or indirectly, through (2) reduced plant water consumption or (3) the combination of both. Studies are very much needed that will provide an answer on the contribution of CO_2 fertilization on water consumption of crops.

2.2.2 Irrigated agriculture

Increased food production can potentially be achieved by different routes but the role that irrigation needs to play is important to understand. The following research issues can be identified:

Global opportunities irrigated agriculture

The 2008 spike in food prices coincided with the end of a period of approximately twenty years during which there was almost no growth in irrigated area. This increase in food process has prompted the World Bank to resume investments in irrigation development. It is probably unlikely that the needed increase in food production can be achieved without significant increases in irrigated agriculture. An obvious and important question then becomes where in the world such development can and/or should take place.

Less densely populated areas (Americas, sub-Saharan Africa, Central Asia) would seem to be the most obvious candidates but each region has important drawbacks. In North America, irrigated agriculture seems to have peaked and further expansion there is unlikely due to declining groundwater tables (Ogallala aquifer) and environmental flow requirements. Expansion of (irrigated) agriculture in South America may come at the cost of important losses in bio-diversity rich ecosystems. Central Asia has seen a decline in irrigation development since the breaking up of the Soviet Union and does not have a good environmental track record either. Africa, and especially the savanna zones, may be the most promising from a physical point of view but earlier attempts have stranded in issues of poor governance and low returns on investments. A quantitative analysis of potential irrigation development and associated drawbacks would be a first step towards a better understanding of the food and water issue.

Stressors on irrigated agriculture

Throughout the world, we see examples of a decline in irrigated areas due to unsustainable practices within, and external pressures from without irrigated agriculture. Depletion of groundwater is perhaps the most urgent stressor. Both the Indo-Gangetic and North China plains show water tables declining at alarming rates. Large scale trans-basin water transfers are seen as possible solutions but it is doubtful such measures can be much more than partial fixes. Decline in water and soil quality through accumulation of salts and agro-chemicals is a second important stressor. Thirdly, in many densely populated areas in the world, such as the rice growing areas of Asia, irrigated agriculture declines due to urban expansion. Finally, the competition for water from other sectors increases further, not only due to urban and industrial development, but also because of the higher value put on environmental water uses. The West of the United States is a clear example. The gravity of all different stressors and their development over time and space would be an important research theme.

New technologies for irrigated agriculture

Irrigation is about as old as sedentary agriculture and no miracle technologies are to be expected. Still, the efficiency of irrigated agriculture can be greatly enhanced by supporting technologies. Genetically Manipulated Organisms may be helpful to reduce water demands but early results for GMO maize have been somewhat disappointing, showing only relatively small increases in production under water stressed growing conditions. In arid areas, water re-use will continue to increase but research on better water and soil treatment methods remains needed. Precision agriculture, from plant to parcel scale, will increase water productivity and reduce environmental stress through better control on accumulation of agro-chemical and salt. Remote sensing and ubiquitous sensing will be important technologies to improve irrigation efficiencies.

2.2.3 Fresh water and fishery

Value of fresh water fisheries, especially in developing countries

The value of fresh water fish has for a long time been neglected. For most inhabitants of developing countries, however, fish is the main source of animal protein. An early example that showed the importance of fisheries was provided by Ringler (2001) for the Mekong River. All alternative water uses in the Mekong, including hydropower, had lower economic returns than the present fisheries. The global importance of fresh water fisheries, and their effects on diets of people in developing countries, is not yet clear. Over the past decades, many developing projects have tried to improve fish production. Scientific analysis at regional to global scales, including yield gaps, is still needed.

2.2.4 Water and livestock

The most important research issues regarding Water and Livestock are:

Livestock and water productivity

The concept of water productivity has gained quite some attention over the last years, but is still largely unexplored in the context of livestock. This livestock water productivity does include all water use so direct drinking as well as water required to produce feed. Obviously, this item is mainly relevant in areas where water is scarce. The following research activities are relevant:

1. Global scale assessment of livestock water productivity with strong emphasis on spatial and temporal resolution.
2. Assessment of the possibility of alternative use of livestock water consumption in semi-arid regions

Livestock and water quality

Especially in the developed world livestock is seen as an important polluter of water. Policies are defined and strict regulations are being implemented. However there is a debate whether these regulations take into account local specific conditions. Based on this chapter the following two research areas are relevant in the broad context of livestock and water quality:

- Impact of livestock on water quality is a completely unexplored area in the developing world. Research might identify potential problems which might lead to policies before severe damage will take place.
- Spatially distributed research on the impact of livestock on water quality.

2.3 Urbanization and infrastructure

(Authors: Thomas Kluge, Engelbert Schramm, Rudger de Graaf)

Urban water management is hitherto founded upon a central system of water supply and sewage disposal facilities and networks which evolved over the last 150 years. Until now the generally accepted rule was that in areas with mid to high population densities, centralized and uniform throughline reactor systems held decisive technical and economical advantages differentiated systems. Nowadays conventional urban water infrastructure systems are increasingly coming under pressure. Changing boundary conditions led to problems for which the undifferentiated concepts offer solutions which seem to be not suitable. New technological solutions claim to solve the challenges of water supplies and sewage management. The subject if there will be a paradigm shift in water management (cf. Hiessl 2005, Otterpohl, Oldenburg 2002, SWITCH 2006) is being discussed in most industrial countries.

Viewing the international literature addressing the topic of models and practical projects for the transition of water infrastructure, it emerges that a few essential driving forces can be seen as the decisive factors:

- Sustainable development
- Climatic change
- New technologies
- Demographic change
- Urban regeneration projects
- Severe resource problems
- Integration of infrastructure and spatial planning (cf. Scheele et al 2008).

Rising energy prizes (due to economic growth resp. future shortage of fossile energy resources) might be another driving force (Kluge et al. 2009). In a regional perspective the problems encountered as well as the dominant drivers are diverse: In Germany the up to now predominant topics are demographic shrinking and sustainable resource management. In other countries thought is being given to alternative supply and sewage disposal concepts, either because a sustained high settlement pressure (Singapur, Japan) or because of the effects of the proposed climate change creates problems with the continuation of the supply and sewage disposal models used to date (Australia, parts of the United States of America). In parts of the United Kingdom a combination of severe resource problems and urban regeneration will lead to new models of urban water management. This section presents the (preliminary) results of our desk research compressed as headlines with some annotations. Some results of the work of de Graaf (2009) are worked in that second draft of the paper. The survey will be completed with the help of some expert interviews and reconciliation with Nick van de Giesen and his group.

2.3.1 Improving system knowledge

Urban regions and their material metabolism as social-ecological systems: Food, water and energy (colonization of the hinterland or autarchy)

Urban agglomerations are marked by an enormous metabolism with their hinterland and this applies for water and energy as well as food. From a technical point of view it is currently becoming possible to model blue and green water not only at state level but to analyse smaller units as well. This way it is possible to undertake a close analysis of the town-hinterland relations in order to find out what kind of ecological backpack is brought into town along with the food and what kind of dependencies exist between a town and the water supplies of its hinterland. In a similar way virtual water could be taken into consideration in order to examine where successful water saving is sabotaged by externalising production steps. As a next step it would be possible to assess in how far this is water efficient.

Water consumption and virtual water consumption of (post)industrial urban regions: Water efficiency in regard to virtual water ("green" and "blue" water)

At the same time it is possible to view this (supra) regional metabolism as a social-ecological system. In light of the climate change and other shifting framework conditions it is necessary to examine how these systems can be run without losing their resilience. With the aspects of regional politics in mind one will have to ask how future exchange relations between a town and its hinterland can be organised in a just way and how the effects of "colonisation" (Fischer-Kowalski & Haberl 1993) can be levelled out.

Problems in basic data for an hydological analysis of the city

Hydrological speaking, urban areas are blind spots. Many traditional measurement protocols are not valid in cities. Rain has to be measured away from buildings, which is impossible in a city. We have good models of sewage systems, but lack data on their functioning, especially during critical rainstorms. Evaporation and groundwater seepage are never monitored. For urban agglomerations it is no longer negligible that they are (a relevant) part of a watershed. Hydrological process knowledge has to be collected in urban watersheds. The role of urban areas in the water cycle is an interesting research theme.

Energy consumption of the urban water infrastructure system and reduction potentials

The issue of economic energy consumption within an urban infrastructural system seems to be trivial at first sight. Indeed countless public utility companies are able to state the overall energy consumption but are unable to determine similar data concerning particular interstations (as for example the lifting energy within the cycle of water catchment). Potential possibilities for saving energy do not only arise from restructuring sewage plants (for instance the extraction of biogas) but also as a result of further declining consumption which makes it possible to optimise networks. The energy amount for transporting drinking water from distant delivery regions to an urban region is about 6 kWh/cubic metre. The transport amount in long distance pipelines, but also in the urban distribution network is a topic neglected in the past, but of high relevance to the utilities. Rough figures for the treatment of grey-water are approximately about 1 kWh/cubic metre. Therefore under certain spatial conditions a grey-water reuse might be favourable compared to long-distance drinking water supply for all purposes. From an energetically point of view the substitution of drinking water by service water might become preferable in densely populated districts of urban agglomerations.

Energy and carbondioxide balance of water technologies have to include comparative life cycle evaluation of (conventional and alternative) urban water infrastructures

The energy efficiency and the potentially negative greenhouse effects of new water technologies compared to conventional technologies is something which has to be closely examined. In this context a life cycle analysis (LCA) has to be included in order to improve the ability to assess in what kind of scale certain future technologies should be implemented (centralized, semi-centralized, decentralized scale). Life cycle analysis is an important tool for both analysing processes to find ways to improve them, and assessing materials and products. Conventional LCA consists of two components: inventory analysis and impact analysis. Inventory analysis involves summarising the material and energy flows for a defined system. Such a system typically includes all of the processes associated with the extraction of resources, supply of energy, manufacture of the product, use of the product and disposal and recycling. The resultant inventory is a list of the resources consumed and the emissions associated with the system.

Impact assessment involves interpreting the significance of the resource consumption and emissions determined in the inventory stage. It should be noted that in life cycle assessment, these are restricted to environmental impacts. LCAs of components used in water technology are well established, e.g. of rain water tanks ouf of different materials (steel, polymers or concrete). But in an urban water infrastructure different components and processes are inseparably combined. In 2008 the first LCAs have been started investigating alternative water infrastructures. Despite of a certain weakness of the LCA approach in some cases LCA has been combined with other methods. In a Danish project the goal is to establish a scientifically based platform to support decisions regarding emerging alternative water management technologies. This will be achieved by improving tools to make LCA of the use of alternative technologies and resources; evaluating selected new technologies and resources by life cycle analysis (including e.g. resources,energy and chemical consumption, accumulation of dangerous residual chemicals and microorganisms, emissions of pollutants and working environment); conducting quantitative risk analysis of integrated system solutions for selected cases, e.g. application of integrated water management in a quarter of the city including rainwater harvesting, direct recycling of greywater and infiltration via engineered wetland for groundwater storage and recovery. An increasing shorter distance in space and time between dirty and contaminated water and high quality and safe drinking water are strongly increasing the consequences in case of failures in the system, but may also lead to a low but continuous risk for the consumers. The goals of such risk analysis are e.g. to estimate the risks of each technology, to estimate the effect on public health, and to estimate the health risk for the individual consumer.

The water infrastructure as energy storage system

In Switzerland heat exchange has for a long time been practiced within the sewage system for reasons of energy autarchy. The sewer network is also a geothermal collection system; one will have to examine how and where the heat contained in wastewater can be used best. For this purpose parallel examinations with different starting points are possible (for example decentralized for the grey water discharge of a single house, semi-centralized in a sewer).

Methane emissions of anaerobic wastewater treatment

The procedural courses in anerobic plants dealing with wastewater treatment have to be considerably opitmised with resepect to their methane yield resp. methane emission during the following water cycle. In Central Europe the inlet temperature of the water is a specific challenge for a sufficient anerobic treatment.

2.3.2 Impacts of climate change and urbanization

The understanding of adaptive capacity of urban water infrastructure and the role of the water cycle in the climate adaptation of urban regions

Various examples have been described to improve the climate robustness of cities with regard to droughts, heat stress and flooding. For instance, Van de Ven et al. (2008) have identified 150 measures that reduce the vulnerability of urban areas. With regard to flood proof urbanization, these measures include wetproofing and dryproofing of buildings and infrastructure, building on mounds, building on stilts, constructing a higher freeboard between roadlevel and floorlevel, flexible and removable constructions, amphibious housing and floating urbanization. De Graaf et al. (2007) defined a robustness framework as a combination of four capacities of a complex system to decrease vulnerability, these are: threshold capacity, coping capacity, recovery capacity and adapting capacity.

Water buffering and water banking will become important instruments for urban climate adaptation management. Suitable arrangements (for example cutting off urban creeks from the sewage system, rain water harvesting via stagnant waters) will make it possible to relieve the water infrastructure and locally improve the urban climate thereby softening the effects of the climate change within towns. These urban ecological points of view have so far not been systematically included into the discussion regarding the transformation of the water infrastructure. To support plans in this direction according models are missing which are integrating the climatologic and the technical economic situation.

2.3.3 Improving target knowledge

Understanding of sustainability

According to many researchers urban water infrastructures should be structurally transformed because they are unsustainable in particular with regard to nutrient recycling and water efficiency (e.g. Otterpohl et al., 1992). The widely used definition of sustainable development from the Brundtland Report (WCED, 1987) is that ‘sustainable development is meeting the needs of current generations without compromising the ability of future generations to meet their needs’. Definitions that are used in urban water management describe sustainability as a balance between social, economic and ecological values. A sustainable approach should include sufficient flexibility in the system to accommodate future changes (cf. de Graaf 2009). The concept of sustainability, however, still lacks consensus about the exact meaning.

2.3.4 Improving transformation knowledge: Development of measures and strategies

Portfolio of water sources

By using a ‘portfolio’ of multiple water resources, including local resources and external resources, urban areas become less dependent on one source of water that might be disrupted in the future. Local water resources contribute to reducing vulnerability by strenghtening coping capacity, recovery capacity and adaptive capacity. According to the Australian Prime Minister’s Science Engineering and Innovation Council Working Group (2007) this approach is a: “move from reliance on traditional sources to an efficient portfolio of water sources which can provide security through diversity. Like a share portfolio, flexible and cost-effective access will be underpinned by diversity, including centralised and decentralised infrastructure. A diversity of water sources underpinned by a range of centralised and decentralized infrastructure providing cities with the flexibility to access a ‘portfolio’ of water sources at least cost and with least impact on rural and environmental water needs.”

Interlinkages with other urban infrastructure systems (energy, waste, urban gardening)

According to Niemczynowicz (1999) the future challenges within urban water management will be to organize cross-sectoral stakeholder cooperation in order to introduce innovative water technologies, management systems and institutional arrangements. These systems should be able to meet the multiple objectives of equity, environmental integrity and economic efficiency, and at the same time achieve a high level of water services.

Mouritz (1996) argued that the design of future water infrastructure should be developed by integrated planning and management of land, water and other resources. Also Van Rooy et al (1998) stated that water is a part of our environment and that water policies interact with urban planning policies. In addition, each development should aim to improve the functions of natural water system to maximize local environmental and economic benefits (Ellis, 1995).

In the last 150 years there was a division of labour: This lead to isolated optimizations of each of the following systems: Water supply, sewage water disposal, energy supply, waste disposal and urban gardening. Institutional fragmentation has resulted in functional silos in which part of the system is optimized in isolation of other system components. This has led to a suboptimal overall system performance. Technical optimization of a component of a large technical system may prevent system innovation. Moreover, it may lead to a technical and institutional lock in. Different organizations are responsible for the interrelated components of urban water systems. Fragmented accountability frameworks of urban water organizations leave limited room for action that diverges from statutory responsibilities. Institutional objectives of urban water management organizations are focused on performing prescribed task within legal frameworks. There is no defined responsibility for the overall urban water system. Reward mechanisms are based on fulfilling procedures, within the boundaries of projected costs and projected timeframes (de Graaf 2009). Possible interlinkages between the systems have not been regarded. On the long run the integration of organic waste (biodegradable section of waste) in urban sewage treatment plants might be lead to synergies and more efficiency in the processes (Kluge et al. 2009). Processed wastewater and improved sludges might be used in urban gardening. Irrigation with used water will shorten the demand and stabilize the urban ecosystems needed for urban climate adaptation. In the past the role of nutrient cycling from wastewater or sewage sludge was over-estimated. Recent dissertations carried out at the Universities Hannover and Darmstadt prove that the efficiency of nutrient cycling is far less as considered hitherto. Only a change in boundary conditions caused by the predicted shortage of P or K minerals or by high energy prizes (fixation of N via Haber/Bosch process) will promote to process urban sewage water in such a way that it will be reused as a risk free and good practicable manure in future agricultural and urban gardening systems (de Graaf 2009).

Integrating fragmented urban development process

Next to institutional fragmentation, also the urban planning process itself is fragmented. Western organizations often apply the serial planning approach. This approach is characterized by fragmentation of the urban development process in distinct steps of policy, planning, design, construction and maintenance. For each step, different stakeholders are responsible that are not involved in previous phases or follow up phases. The result is that communication between the phases takes place in the form of reports, documents and guidelines. Only transfer of explicit knowledge is possible and other forms of knowledge (e.g. tacit knowledge) will not be transferred to the next phase of the process. Original intentions of the policy are lost in the design phase when feasible measures are desired.

Governance, adaptivity and technological steerability of an integrated urban water system

The implementation of innovative solutions is hindered by institutional barriers and technical lock-in effcets. On the other hand, environmental and hygienic laws and recommendations are the drivers of innovations in urban water technology. To successfully implement new concepts and new technologies, they must be embedded in the socio economic system, that is: user practices, perceptions, guidelines, legal frameworks and markets. In recent years, researchers have become increasingly interested in the ongoing transformation of urban water systems. Changes in the urban water management approach can be classified as paradigm shifts, transitions, regime shifts or transformations (Van der Brugge & Rotmans 2006; Brown & Clarke 2007; SWITCH, 2006). The effects of climate change and developments such as urbanization, the European Water Framework Directive, and societal concerns about the sustainability of urban water system force the sector to adapt. Stakeholders are becoming more involved in urban water management. Urban water systems have to fulfil an increasing number of functions and are influenced by various conflicting values. Thus, the connection with urban planning and development, that is the process through which spatial functions are determined and values are negotiated, is increasingly important. Concepts such as Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID) and Integrated Urban Water Management (IUWM) reflect approaches in which the connection with urban planning and social amenity is highlighted. Most approaches stress the necessity of an integrated system approach that includes the total urban water cycle. The components of the urban water system are interrelated. Therefore, wastewater, stormwater, drinking water supply, groundwater and surface water should be studied and managed by using an integrative approach. An important element in this approach is the use of an integrated, cross-sectoral, multidisciplinary institutional framework (e.g. Butler & Parkinson 1997; Niemczynowicz, 1999; Geldof and Stahre, 2006). Some authors consider the urban water system as a complex adaptive system (Geldof and Stahre, 2006) or socio-technical system (Brown and Clarke, 2007) rather than a technical system. Not only can the metabolism with the urban hinterland but also the urban water system as such be seen as a social-ecological system. So far analyses concerning governance, adaptivity and technical controllability of the infrastructure as a complex adaptive or social-ecological system are missing.

Integrative evaluation of alternative water systems (how to weighten social, economical, institutional and physical effects?)

The financial relation of alternative water systems to the conventional ones should be researched carefully because the existing systems currently work satisfactory in relation to the users charge. On the other hand some model project shows us that there is a willingness to pay for a more sustainable technology. The assessment of sustainable sanitary systems and similar systematic alternatives so far had its focus on the economic technical side. A systematic integration of social, economic, institutional and physical effects (for example with Bayesian networks) has up to now not been attempted.

Generalizing and scaling up of references projects (from the sewage free house to the water autarchic city district)

In Germany, there have been noteworthy innovations in the past two decades in the field of alternative water supply and sewage disposal technology. To date, however, these innovations have only been implemented in a few, small-scale pilot projects. The specific experiences gathered through experimental housing and urban development projects do not, however, provide sufficient basis to draw general conclusions or do not indicate that the innovations are applicable in current terms for implementation on a larger scale and combined with existing facilities and networks. So we come to the conclusion that there are experiences and projects at different spatial levels, predominantly on the level of single objects. Up to now there were a number of model projects, in which alternative ways of handling water have been tried out. But there is no systemic effort of activities. Often there are only general statements on the need for transitions; the analyses top priority is in identification the pressure to action and necessity to adapt. In the first place, the international debate is on sustainable infrastructure, assessment and methods. Comparing centralized and decentralized systems under aspects of sustainability lacks adequate empirical data. There is also a deficit in research on effects of new technology concepts on existing urban structures. But a systematic transfer onto a larger scale (town district, town as a whole, agglomeration area) is painfully missing. Learning mechanisms to evaluate, improve and replicate niche projects are essential. Demonstration projects are often isolated showpieces, they lack coherence, are not monitored, and are not evaluated. Consequently they are not replicated and fail to influence mainstream practice. For this purpose there should be incentives and rewards for evaluation. These incentives should be built in the design of demonstration projects. Only when large scale projects are realized, will it be possible to market new water technologies (also globally) and to tackle necessary product developments (for example functioning bowls for no mix toilets).

2.3.5 Improving transformation knowledge: Implementation and mainstreaming

Capacity development/mutual learning of urban water agencies (incl. utilities and municipalities) and citizens

The active participation of the users is essential if local or regional solutions are to be adopted. Pahl-Wostl (2006) listed a number of essential attributes for meaningful citizen participation including: access to comprehensive and timely information, capacity building and empowerment of citizens, reform of institutional settings to allow citizens to articulate their perspective, involvement in both envisioning of future management schemes and daily management. In addition, user fees could be made dependent on the effort made on private property to contribute to the overall system performance (Parikh et al., 2005). Citizens may play a more active role that the passive consumer in the provision of urban water services for instance as a producer of local water resources (Hegger, 2007). Whereas in the past, relations to smaller clients and users were defined as a case for logistics, utility companies now acknowledge that they are not sufficiently aware of the users’ way of thinking. Only in a process of mutual learning will it be possible to establish a successful Demand-Side-Management. In order to swiftly spread innovations, measures of capacity development on different levels (technicians, merchants, PR people, workers) will be decisive. It is remarkable that these measures have so far hardly been coordinated.

Transition management of the urban water infrastructure (nutrient cycling vs. energy recovery; demand side management as a means of gaining new flexibility; adaptive management)

According to an international expert discussion "Sustainable Urban Water Infrastructure – Possibilities of Adaptation and Transformation" (2008 in Berlin, Germany, organized by the Net-WORKS group) there will be severe changes in urban water management in the next 20 years: Approaches of a differentiate way of coping with water (e.g. supply with process water, separated treatment of black and greywater) are no longer only a subject of so-called pilot projects, but, against the background of the changing boundary conditions (e.g. adaptation to climate change), will become more relevant in built-up areas. Researchers from Australia, China, France, Germany, the Netherlands, Sweden, Switzerland, Israel and the USA have confirmed that the central question of a purposive design of the transition to a new infrastructure system is of high relevance and should be observed more intensively. One of the challenges will be a management for this transition process allowing "good governance" for the municipalities and their utilities. The institutional capacity to implement and maintain innovations is an important element for the transformation of urban water systems (Söderberg and Johansson, 2006; Wong, 2006). Pahl-Wostl (2006) stated that the shared knowledge of professionals combined with expectations of stakeholders causes a status quo in the water system. According to her, the inertia in the technical system and the social rules and habits are obstacles to change. Brown et al. (2009) conducted an extensive international literature review on socio-institutional obstacles that prevent urban water management from changing. They found 12 barrier types that were mainly related to insufficient capacity and commitment of urban water management stakeholders to change their way of working. With new technological decentralized options it will be of course possible to cherry-pick from the urban water system (for example the case of office high-rise buildings: the wastewater of which being pre-treated by a private company such exploiting its nutrient and energy content in the process). This can have the effect that the remainder of the infrastructure can only be used in a less efficient way. For the transformation of the urban water infrastructure integrating models are missing to coordinate networks. These models might help companies to investigate georeferentially on town-district level at what point in time a renewal/modernisation might be preferable and also help to find out how a possible privatisation of tasks within the range of fresh water supply and wastewater disposal should be structured. Transformation management should also cope with changes in the institutional capacity and the synchronization of settlement investment cycles (e.g. revitalisation of certain city districts) and water infrastructure investment cycles.

Mainstreaming

As mentioned above, one of the central restrictions for a transformation towards sustainability lies in cognitive capacities which have to be developed. To promote a transformation of urban water management, changing professional practice is mentioned as an important element. Also, receptivity to both technical innovations and policy innovations is a determining factor for application of these innovations (Jeffrey and Seaton 2004). Jeffrey and Seaton (2004) defined receptivity as "the extent to which there exists not only a willingness (or disposition) but also an ability (or capability) in different constituencies (individuals, communities, organizations, agencies, etc) to absorb, accept and utilize innovation options." For mainstreaming of new professional practices and alternative technological options, four attributes are required according to the receptivity framework:

- Awareness: being aware that a problem exists, and that alternative options are available
- Association: associate these options with the stakeholders own agenda and objectives
- Acquisition: being able to acquire, implement, operate and maintain the alternative options
- Application: having sufficient legal and financial incentives to apply the alternative options

The understanding of the capacity of social environment in which policies or technologies are to be implemented is crucial for the success of implementation. The technology or policy should fit into the values, knowledge and capacities of the recipients of change programs. Receptivity analysis focuses on the perception of those who are to implement a new technology or innovation. Jeffrey and Seaton argue that: "It is not possible to understand the response and behavior of people to an artifact, situation or policy instrument without understanding their perceptions, attitudes and the agendas for change that are relevant for them." Current reform interventions in urban water management often fail to address the complete range of receptivity. They seem to be focused on creating awareness or stimulating of application by legal reforms and subsidies. Therefore it is not surprising that these programs have received criticism for not being effective (Brown & Keath, 2008). The focus on awareness and application may be explained by the clear, short term results that these programs aim to produce. An awareness campaign or a new subsidy program can be implemented relatively quickly and is a short tem identifiable action for public decision makers. On the other hand, creating association and acquisition among stakeholders is a long term process without clear short term results. Changing conventional practice requires strengthening four components of institutional capacity: (Brown et al. 2006)

- Human resources: implicit and explicit knowledge, skills and expertise available
- Intra-organisational capacity: processes, systems, culture and resources within organizations to cooperate
- Inter-organisational capacity: agreements, relationships and networks the exist between organization to cooperate
- External institutional rules and incentives: the regulations, policies and incentive schemes

At least the following research questions are identified:

3. How can the receptivity of stakeholders to urban water management innovations be improved to facilitate the adoption of sustainable urban water management?
4. What kind of capacities and skills of stakeholders are essential to enable mainstreaming of urban water management innovations?
5. What are mechanisms that facilitate the transfer of knowledge from technical demonstration projects to mainstream professional practice in order to make a system wide impact?

6. How can entrepreneurs and private investors be stimulated to contribute to the transformation of cities when adapting to climate change?
7. How can citizens be meaningfully involved in transforming cities to adapt to climate change?
8. How can organizations be enabled to participate in climate adaptation programs with multiple stakeholders and multiple functions?
9. How can the sense-of-urgency for long term urban water management problems be increased in urban development policy?

2.4 Disasters and vulnerability to water related threats

(Authors: Jörn Birkmann, Niklas Gebert)

Vulnerability is the (a) intrinsic and dynamic feature of an element at risk (population, community, region, state, infrastructure, environment etc.) (b)…that determines the expected damage/harm resulting from a given hazardous event. (c) Vulnerability changes continuously over time and (d) …is driven by political, institutional, physical, social, economic and environmental factors. (UNU-EHS 2006). Adaptation strategies, and other climate change related policy documents e.g. in the area of IWRM, and vulnerability assessments have in general developed in parallel, without major connections. Often there is a lack integrated approaches or a clear understanding on how to reduce vulnerability (Chapter 2.2). Although, these shortcomings have their roots in the deficiency of international adaptation politics also the vulnerability assessment community did not develop methods and tools that could be of use for e.g. NAPA's implementation monitoring. Developing knowledge based tools that provide decision makers with opportunities to construct scenarios options promotes the emerging guiding principle of adaptive management / governance. Thus, the shortcomings of up-to-date vulnerability science and assessments are as follows:

2.4.1 Hazard

Under climate change conditions natural hazards and a combination of man made and natural hazards are likely to increase. Already now regional climate change scenarios can coarsely locate future dangerous climate change effects, such as the occurrence of drought and flood events. Many regions in the world will face at the same time an increase in the frequency and magnitude of already known hazards, new hazard types and a multi-causal combination of multiple hazards occurring and affecting people, cities and regions.

Up-to-date research mainly focused on single hazard event prediction with a deterministic approach or probability function for its occurrence, magnitude, frequency. Under conditions of uncertainty, the probabilistic approach is questioned or needs to be linked up with <u>scenario driven assessments</u> (e.g. floods and sea level rise) that also require a strong involvement of stakeholders, decision makers and the general pubic (UN-Water 2009, p 74f). The increasing recognition of the need for a <u>multi-hazard perspective</u> in disaster, vulnerability and climate change adaptation research requires also the knowledge of seasonal differentiated hazard specifics and cascading effects (secondary hazards) and their interplay with man made hazard triggers as a consequence of global change. This implies also to understand more the interdependencies between the human induced and climatic induced dimension of hazard triggers.

Looking at future climate change long-term trends: are regions rather facing slow and <u>long-term climate change</u> while others suffer from <u>intense climatic variability</u> causing extreme events? Accurate and spatial hazard modeling is important for risk analysis and understanding impacts and vulnerabilities, and <u>developing crisis management systems and prevention tools</u>. In this respect, e.g. the knowledge on modeling flood specifics such as water depths, velocities and duration of occurrences is required, especially also taking into account the effects of flood protection infrastructures on e.g. downstream exposed areas.

2.4.2 Exposure development

Exposure related research questions ask for how to quantify and assess exposure but also how exposure is generated. On the one hand the hazard / climate change determines the geographic / spatial location of exposure. On the other hand as exposure is being part of vulnerability, it relates to the underlying factors and driving forces that allow elements to be (e.g. populations and infrastructures) exposed.

Very much research has been conducted to determine and quantify the level of exposed populations and other human and environment system relevant subjects and objects. With a given hazard scenario and more or less accurate estimation of the spatial distribution of a hazard specific exposure is assessed by counting, locating and mapping exposed objects of interest such as population, physical structure and ecosystem distribution.

Exposure intensification and trends of exposure development

Future research needs to address the dynamics of exposure and its underlying factors. This includes integrative research on regional and local trend analysis of population development, in relation to economic trends, natural resource utilization and institutional framework conditions specifically in the globalization context.

Man made exposure generation

Here, not only the natural hazard – exposure nexus shall be looked at but also at the dynamics of man made (natural) hazards, especially caused by natural resource depletion (e.g. deforestation causing floods or droughts / fire) as a consequence of natural resource exploitation and (mal-) land use planning such as structural measures (e.g. flood protection) that aim at reducing exposure in a certain area but generating new exposures and vulnerabilities in another. Thus, research need to identify the hotspots and archetypes of global and environmental change interlinks, as well as temporal and spatial exposure dynamics.

Indirect exposure

In addition the question is whether the geographical area of exposure equals the hazard area or the impact area of a given hazard or climate change region. E.g. the damage to the economy / population / infrastructure of a given area has impacts on other areas due to its regional integration. Thus, research shall focus on world and nation wide effects of anticipated large scale flood or drought events.

Exposure manifestation

Less research has been conducted on risk as an advantage rather than a threat. What are the predominant driving forces and patterns of livelihood strategies in multiple risk environments, such as income and social insecurity, and limited choices?

2.4.3 Vulnerability of the population

Vulnerability of the population is the intrinsic and dynamic feature <u>of actors and social groups</u> that contribute to the likelihood of their injury, ill health, loss of life and livelihood resulting from water related hazardous events. The vulnerability of the population <u>changes continuously</u> over time and is driven by political, institutional, physical, social, economic and environmental factors.

Understanding factors for loss of life and livelihoods, injury and ill-health are at the centre of population related disaster studies. Not all exposed societies and populations suffer the same amount of loss. Thereby, the focus is on actors, social groups their distinct attributes and features that determine their capacities to deal with disaster. Key scientific expertise is provided by social science, human geography, psychology and anthropology. Lots of research with in quantitative vulnerability assessment has been conducted to link people's social and demographic attributes, such as age, gender, health, education, income, norms and values and other factors to the likelihood of suffering damage, injury or loss of life from a hazard event. Vulnerability studies with a focus on mapping vulnerability with a great geographical coverage lack appropriate data, because vulnerability specific social and demographic data for the micro scale are not collected by national statistics. Thus, current population related vulnerability research is limited but needs improvement.

Localization of demographic and social trends

Static and partial screenshot analysis of demographic and socio-economic indicators of vulnerability exists but they lack high spatial resolution and coverage. Here, methods are needed that also can indicate robust trends for future developments.

Human loss estimation

Crisis Management needs accurate figures of potential direct human losses for developing contingency plans.

Societal discourse analysis: Conditions for transformation and adaptation

A special focus is needed that investigates the macro forces and transforming processes that shape the mode of individual and collective risk perception and evaluation, risk communication, social learning, memory and cultural identity. How are individual and collective guiding principles of a society defined and transformed into action under certain framework conditions such as globalization, market integration, economic growth paradigm, individualism and modernity? Do these societal transformations yield a progression of unsafe conditions and collapse, triggering further the likelihood of water pollution, water scarcity or flooding?

2.4.4 Economic vulnerability

Economic vulnerability is the intrinsic and dynamic feature of the economy that determines the expected damage/harm of the micro-, macro and household economy resulting from water related hazardous events. Economic vulnerability changes continuously over time and is driven by political, institutional, physical, social, economic and environmental factors. Economic vulnerability is likely to have complex negative effects on overall human security. (adapted from UNU-EHS 2006)

Such as critical infrastructures also economies (macro-economy) and businesses (micro-economy) are likely to be affected by climate change and water related natural hazards, also in not exposed areas (indirect exposure). The economic vulnerability of a region depends on its regional integration, physical direct and indirect exposure and on its capacity to absorb shocks and to recover from them. Water related economic damage to households, enterprises and national economy is one of the most important vulnerability topics, since all development efforts of societies are based on market economic solutions. Economic exposure and vulnerability research needs to distinguish between Macro-economic vulnerability, Micro-economic vulnerability and Household economic vulnerability. At the centre of all three dimensions of economic vulnerability is the question whether business continuity of small, middle and large-scale enterprises can sustain during crisis occurrence. If this is the case, households (aside from income diversification strategies) and macro-economic developments are less likely to suffer long-term damage and thus enable societies to remain in function.

Economic vulnerability research up to date focused very much on estimating potential economic damage as a result of flood disasters. This is done by estimating the direct economic values of all kinds of physical assets and produced goods and services in the exposed locations to a given hazard such as flood. Besides this, economic vulnerability research has also been conducted on how much funds at the national level are available to cover the costs for reconstruction of disasters and what the long-term financial losses are (e.g. CATSIM). So far in the past (proxy) economic vulnerability indicators and indexes have been developed that were merely linked to their specific function (disaster risk reduction).

Tools for economic disaster risk reduction

Little research has been systematically conducted in the different classical economic research domains of micro- and macro-economics. There is a strong need of vulnerability assessments that shall be specifically designed for important disaster risk reduction tools to be applied by the public and the private sector and households. Such tools can be developed for the different actors regulating economic processes and risks:

The public sector: Cost-benefit analysis of planned financial investments in disaster risk reduction measures (e.g. early warning systems vs. relocation, structural measures vs. non structural measures)

The private sector: The concept of "Business Continuity Management" (BCM) is a new field of intervention in the private sector with the goal to develop efficient crisis management structures to prevent and manage damage to businesses in emergency situations. The need to develop vulnerability assessment methods for businesses emphasizes the importance to create situational awareness to company owners about the structural weaknesses of their company that can lead to loss and long-term failure of basic functions. Based on the assessment strategies for BCM can be developed that include the development of resource supply redundancies, implement structural / physical measures etc.

All sectors: the public, private and households: Risk transfer and insurance schemes that enable quick compensation for recovery and business and livelihood continuity. For the development of such schemes the different exposures and vulnerabilities of the different economic sectors and enterprises (small to large) and household types (poor to rich) need to be known with respect to (1) their potential economic pattern and (2) their ability to participate in such schemes.

Indirect economic damage and effects

At best decision makers could get an idea of the potential direct financial losses taking a specific hazard scenario. Direct economic damage has been estimated by estimating the value of a specific enterprise or calculating the loss of direct productivity.

Little research has been conducted to estimate secondary effects of economic damage. The knowledge on secondary effects such as unemployment, the failure of trade or basic service supply is needed in order to avoid crisis manifestation and a general down turn spiral of economic development.

2.4.5 Critical Infrastructure Vulnerability

Critical infrastructure vulnerability is the intrinsic and dynamic feature of critical infrastructures that determines the expected damage/harm of different critical infrastructures (providing basic services to populations) resulting from water related hazardous events. Critical infrastructure vulnerability changes continuously over time and is driven by physical, social, political, institutional and economic and environmental factors. The vulnerability of critical infrastructures is likely to have complex negative effects on overall human security. (adapted from UNU-EHS 2006)

Critical infrastructures play a crucial role in providing basic services to the population. This includes e.g. freshwater and sanitation, electricity, transport, communication and the so called socio-economic service infrastructures such as heath care, food supply, disaster management and public service (BMI 2009). The failure of critical infrastructures affects the economy, income and general livelihoods of direct and indirect exposed populations and is therefore a core research field in vulnerability science.

Recent research has been conducted at UNU-EHS on how to assess the vulnerability of electricity and water supply infrastructures and their components in terms of their likelihood to fail during the course of a flood event. The vulnerability assessment on the component level focussed on the criteria exposure, functionality (under the condition of being exposed), technical redundancy and organizational preparedness. In a relative ranking the results of the component level were brought together according to their relevance for the functioning of the system.

Less research has been conducted on understanding the impact chains and cascading effects of critical infrastructure failures on other supply networks and the population and the economy in especially highly technical, industrialized and service dependent societies. Thereby the interconnection of the vulnerability of critical infrastructures and of the population to critical infrastructure failures is of particular interest. This applies to climatic hazards, large scale droughts and floods.

Future challenges are especially to evaluate the vulnerabilities of emerging innovative infrastructural technologies such as “smart grids” (electricity) to stress such as extreme events and changing climate conditions.

2.4.6 Adaptive and institutional capacities

Governance Vulnerability is the intrinsic and dynamic feature of the institutional fabric of state organization that determines the expected damage/harm of citizens resulting from water related hazardous events. Governance V. changes continuously over time and is driven by political, legal, social, cultural, economic and environmental factors. Governance vulnerability is likely to have complex negative effects on overall human security. (adapted from UNU-EHS 2006)

Adaptive management requires adaptive capacity, which is if not adequately developed a vulnerability factor. The regulation or governance of risk is a new emerging field for social and political scientists. With the focus on uncertainty in all fields of disaster preparedness and prevention the key challenge for regulatory and state driven frameworks is to develop adaptive management capacities. These are not only developed by covering the four fields of risk governance but also by introducing “management policies and practices by learning from the outcomes of implemented management strategies” (Pahl-Wostl 2006).The absence of adaptive management and governance rules and procedures and capacities is an absolute factor for exposure and vulnerability of populations to water related stressors.

Theoretical / conceptual work has been sufficiently conducted to frame adaptive governance and capacities. Adaptive management as a new type of governance is well accepted to face uncertainty such as climate change and variability, extreme event inundations and timescales of their emergence.

Little research has been conducted developing a holistic framework and quantitative tool for assessing adaptive capacity of relevant institutions engaged in non-structural and structural adaptation measures in disaster prevention and crisis management. Quality criteria for adaptive management are to be defined prior to the assessment. But simply assessing adaptive management capacities is not enough: A special research foci need to investigate on the root causes for failures of the development of effective adaptive management structures, this accounts especially for effective implementation. Thus, comparative case studies in both developed and developing countries need to be conducted. Adaptive management processes such as social learning and decision making are configured differently in different cultural and environmental settings.

2.5 Water governance (cross-cutting)

(Authors: Claudia Pahl-Wostl, Nina Wernsing, Johannes Halbe)

Governance embraces the full complexity of regulatory processes and their interaction. This is reflected in the definition of water governance by UNDP: *"Water governance refers to the range of political, social, economic and administrative systems that are in place to regulate development and management of water resources and provisions of water services at different levels of society (UNDP, 2000)"*

The human dimension, long neglected by water scholars and practitioners, increasingly appears to be the most fertile frontier for innovations in research, policy and practice. To assess the current state of development in this direction we made a bibliometric analysis of publications using the SCOPUS data base. Different combinations of key words were used to define "search terms". The search results include the number of publications in peer reviewed journals in the search space "articles and reviews" that included the "search term" in the abstract, title or key words.

Search Term	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Water AND Governance	12	18	36	19	39	59	58	86	106	135
Water AND Policy	482	588	643	712	754	865	901	976	1101	1233
Water AND Stakeholder	58	59	98	94	113	145	164	201	225	250
"Water Management" AND "Governance	2	4	10	5	24	35	26	28	43	62
"Water Management" AND Technology	81	151	127	135	172	213	234	263	319	339
Water AND Technology	1517	1713	1780	1890	2304	2656	3081	3400	4031	4084

Table 1: Number of publications regarding water governance in peer reviewed journals in the search space "articles and reviews" that included the "search term" in the abstract, title or key words

Table 1 highlights the continued dominance of technical over social perspectives. Publications in water-related science show still a decisive advantage for technology over governance, and "water management AND technology" over "water management AND governance". This despite overwhelming recognition that many water related problems have their origin in governance failure. However, one must also acknowledge the increase of publications with a social science focus over the past decade from virtual no publications on water management and governance in 1999 to about 60 publications in 2008.

Another indication of that is that about 50 % of the papers on 'Water Management AND Governance' and 60% of the papers on 'Water AND Governance' are published in as Social Science classified sources. The corresponding percentage of papers on 'Water Management AND Policy' or 'Water and Policy' is only 25%. Social Science classified includes the categories: Social Sciences, Economics/Econometrics/Finance, Business/Management/Accounting, Decision Sciences, Arts/Humanities, Psychology.

The field of water governance work will see an increasing number of publications and research contributions. However, the water research community for social sciences is quite diverse and fragmented, with publications scattered over a wide range of journals. In November 2007 the international Conference on Adaptive and Integrated Water Management (CAIWA) organized by NeWater[4], was the first major international scientific event from and for the social science water community[5]. The special issue on Water Governance in 'Global Governance' was that first special issue in an established political science journal on this theme (Pahl-Wostl et al, 2008). There is a need was expressed to develop a stronger identity as a scholarly community. This poses an interdisciplinary challenge that is seldom met these days, requiring the ability to collaborate with natural sciences and engineering and at the same time to develop own original work in the social sciences. Any new research program should also take the community building contributions into account.

Regarding research topics the following themes can be identified as priority gaps from both the scientific and the policy perspectives. The topics here are of a more general cross-cutting nature. They are partly taken up again and more specified in other thematic areas (e.g. adaptation to climate change, trade-off between water needs for humans and nature) where governance plays as well a key role.

2.5.1 Link across levels

Pahl-Wostl et al (2008) analysed the development of water governance at different levels. Traditionally, watergovernance has essentially been seen as a *local level* issue. The driving forces behind this concept are the notions of decentralization and subsidiarity. Since water problems are local, so goes this reasoning, they should be handled at the lowest appropriate governance level. Another strong school of thought holds that water governance should be regulated at a *national level*. From this perspective water is a national resource that should be governed for the benefit of the national economy and society: domestic interests come first. A third approach to governance of water focuses on the *basin level*. This view argues that water-related problems and conflicts are best dealt with within the natural sphere of the system – that is, the hydrologically defined basin, catchment or watershed. It allows for the internalization of otherwise externalized problems as they arise for instance from up- and downstream relations. A fourth and relatively new school takes a *global* perspective on governance of water. Many water-related environmental and societal problems as well as water use related conflicts elude appropriate solutions at local level or within national or basin boundaries.

All these traditions have developed research communities that analyze water governance related issues at different levels. Hardly any cross level interactions are taken into account in research. However, local, national and basin-level water issues interact and are interlinked within a global water system. The lack of vertical integration in water governance regimes has been identified as a major constraint for developing appropriate responses in climate change adaptation. More studies are needed that analyze the interaction between governance levels and how they affect performance regarding legitimacy, effectiveness and efficiency and adaptive capacity.

2.5.2 Global water governance

The global dimension has gained increasing importance in water governance. Water problems have traditionally been considered to be local or regional problems. However, there are strong

[4] New approaches of adaptive water management under uncertainty. Integrated Project in PRIORITY 6.3 Global Change and Ecosystems in the 6th EU framework programme, 511179 (GOCE).

[5] http://www.newater.info/caiwa/

arguments to take the global dimension into account (Pahl-Wostl, et al, 2008; Alcamo et al, 2008). Not much work exists on global water governance that addresses the question if current processes of global water governance provide the base to meet present and future challenges. In their analysis of the current state of global water governance Pahl-Wostl et al (2008) noted the diffuse and fragmented character of today's Global Water Governance with heterogeneous players without indications of emerging global leadership. The lack of strong motivation within UN agencies and states to push water management has been compensated by rise of pluralistic bodies trying to deal with these issues. UN Water, the coordination platform for water related issues in the UN system, is thus far comprised of functional and nongovernmental agents of various water-related 'partners', not organisations representing governmental units, or the water governance system in and of itself.

Experiences at the various emerging levels of water governance have contributed to an increasing awareness of the need to fill the institutional gap. World Water forums of professionals, experts and field administrators have gradually developed into social movements to fill the institutional void, generating shared norms, ideas and understanding. However, by their very institutional nature these movements, despite their increasing, mass participation and wholesale turn out at peak-events and summit meetings are incapable to generate a collective and mutually binding policy agenda. The mechanisms for generating legitimate and binding collective decisions on future agenda's are lacking.

Required is a research and policy agenda which combines functional global governance scenarios with a thorough, systemic and empirical comparative analysis of multi-level water governance regimes.

2.5.3 Interaction of different modes of governance

Water governance has gone through different fashions of what are preferred governance modes. Initially control by government was the preferred approach. Then markets and privatizations have been advocated as the ultimate solution to any kind of governance failure or lack of efficiency and effectiveness. Such one-sided views have been replaced by an understanding that different kinds of governance modes in interaction (e.g. public private partnerships) may have a better performance than any in isolation. Different countries experiment for example with institutional settings to find a balance between processes of decentralization and central coordination. Water governance regimes where these processes are more balanced seem to be characterized by a higher general performance and higher adaptive capacity (Saleth and Dinar, 2005; Pahl-Wostl, 2009). The relationship between bureaucratic hierarchies and market based approaches and the relationship between bureaucratic hierarchies and network governance have found increasing attention. What is yet largely unexplored is the interaction between the three governance modes - networks, bureaucratic hierarchies and markets. What this could imply is illustrated by an example for water allocation. How can regulatory frameworks, stakeholder negotiation platforms and market based approaches be combined to develop, implement and improve water allocation schemes in water scarce regions?

2.5.4 Adaptive governance

Gaps related to adaptive water governance are dealt with in more detail under the theme "climate change adaptation". Climate change adaptation is a strong trigger for a transition towards more flexible and adaptive water governance regimes and has initiated increasing research interest in the topic. However, the need for adaptive and integrated water governance has been recognized before (Folke, et al 2005; Pahl-Wostl, 2007). This is in line with the general recognition that dealing with complex environmental problems requires different modes of "steering". Command and control approaches have been replaced by approaches that put more emphasis on stakeholder participation and social and societal learning (Pahl-Wostl, 2009). Knowledge gaps remain how adaptive and integrative governance can be achieved without compromising some good governance principles, in particular efficiency, equity, accountability and transparency.

2.5.5 Comprehensive concept

Analysing the dynamics of multi-level and complex resource governance systems is a yet underdeveloped area of research. Development of conceptual and methodological frameworks has not kept pace with the insights on the complexity of the systems to be studied. Major relevant conceptual frameworks in the social sciences (i.e. regime theory in political sciences, game theory, new institutional economics) are quite weak in their ability to analyse the complex, context dependent dynamics of governance regimes (Harrison, 2006; Ostrom, 2007). Most governance analyses focus on static descriptions and embrace only a part of the processes of importance from a disciplinary perspective. Young (2008, p 140) noted in his conclusions from work in the IDGEC (Institutional Dimensions of Global Environmental Change) program that "*Knowledge regarding the nature of change in the institutional dimensions of socioecological systems remains relatively underdeveloped"*. He highlighted further the need for an integrative approach towards analysing governance processes in social-ecological systems from a broad perspective.

This implies that studies on water governance cannot simply apply available frameworks but have to first develop considerable efforts to build conceptual and methodological foundations.

2.5.6 Large comparative studies – data bases

Quite a few claims exist on normative criteria for good governance principles. Hardly any large comparative assessments if and how such normative claims are met and if they lead indeed to a higher sustainability of water management which is the ultimate goal. One notable exception is the comprehensive study by Saleth and Dinar (2004) who analyzed the success of policy reform and institutional performance in the water sector across a large number of countries.

However, we need such approaches to make progress in our understanding and in developing context sensitive policy advice. Panaceas have proven to be weak in their explanatory power and not very useful or even detrimental for policy advice (Ostrom et al, 2007; Ingram, 2008). On the other hand, too specific analyses will hardly lead to insights that can be generalized across individual case studies. What is required may be called a diagnostic approach taking into account complexity in a systematic fashion. Such an approach should support context sensitive analysis without being case specific and thus not transferable.

This requires an interdisciplinary approach in the social sciences and across the social-natural science interface. Both requirements pose considerable challenges to the scientific communities. Interdisciplinary collaboration in the social sciences is fraught with difficulties. Conceptual and methodological foundations are often (perceived to be) incompatible. Shared data bases and protocols hardly exist. These challenges are relevant not only for water governance. Both Young (2008) and Ostrom (2007) make strong pleas to collaborate in professional networks who adopt shared practices to build a knowledge base on resource governance regimes as foundation for dealing with the major global change challenges of the present and the future.

2.6 Ecosystem water requirements – environmental flows (cross-cutting)

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Human use of water can be viewed as direct use, such as water for public supply, irrigation, hydropower production and industry, and indirect use such as the use of ecosystem services provided by water (Acreman, 1998). There are trade-off between allocation of water to direct and in-direct human uses. The hydrological effect of allocation of water to natural ecosystems is frequently positive, as ecosystems provide valuable goods and services, such as water retention and improved water quality. Direct use of water through the development of highly managed systems, including reservoirs, intensive irrigation schemes, dams, river embankments and water purification plants frequently has a negative impact on the hydrological cycle. This has lead to freshwater ecosystems belonging to the ecosystems most threatened by degradation because of human activity.

The most well-described declines in freshwater biodiversity are those of fish and amphibians. However, also other groups are under threat from various pressures related to human activity. Cumberlidge et al. (2009) review the status of freshwater crabs, and conclude that about one-sixth of all freshwater crab species have an elevated risk of extinction, only one-third are not at risk, and although none are actually extinct, almost half are too poorly known to assess. Out of 122 countries that have populations of freshwater crabs, 43 have species in need of protection. The majority of threatened species are restricted-range semi-terrestrial endemics living in habitats subjected to deforestation, alteration of drainage patterns, and pollution. Freshwater crabs can be an important food source and bring income revenue to local fisheries in the tropics.

Dudgeon et al. (2005) review the threats, status and conservation challenges facing freshwater ecosystems. They group the threats into five different classes:

1. Overexploitation
2. Flow modification/fragmentation
3. Pollution
4. Invasive species
5. Habitat destruction or degradation

These threats are often interconnected and may lead to considerable loss of freshwater biodiversity and ecosystem degradation, thus impairing the ecosystem services these systems provide.

Freshwater ecosystems and ecosystem services

Ecosystem services refer to the benefits people attain from ecosystems. The Millennium Ecosystem Assessment (2005) categorized ecosystem services as provisioning, regulating, cultural, and supporting. Provisioning services are the most clearly recognizable of all of the types of services, because they provide direct products people can use such as clean drinking water, protein (fish, shrimp, crabs), fertile land for flood-recession agriculture and grazing, populations of wildlife for harvest, growing vegetables and fruit, fibre/organic raw material, medicinal plants and inorganic raw material such as sand and gravel. Inland fisheries in developing countries may provide the only source of animal protein for rural people (Welcomme et al., 2006).

Examples of provisioning services

While decline in fish stocks has been mostly discussed for marine environment, this is also a problem in freshwater systems. Humphries et al. (2009) review the historical impacts on river fauna and conclude that fish and other aquatic animals were superabundant when Europeans first arrived in North America and Australia, and were intensively exploited soon after. Contemporaneously, the construction of barriers in rivers increasingly prevented many species from migrating. Populations usually crashed as a result. Chen et al. (2009) conclude that the fishery resources in the Yangtze are seriously depleted; the fishery yield by fishing is significantly reduced; significant changes have occurred on the structure of fish community, with decrease in migratory fish species, reduction in the quantity of the populations of rare, peculiar and economically important fish species and increase in the number of exotic fish species, and a severe trend in fish stunting. Habitat fragmentation and shrinkage, resources overexploitation, water pollution and invasion of exotic species are the main causes for threatening fish stocks in the Yangtze River. Holmlund & Hammer (1999) review the role of fish populations in generating ecosystem services based on documented ecological functions and human demands of fish. They show how the ongoing overexploitation of global fish resources is of concern to our societies, not only in terms of decreasing fish populations important for consumption and recreational activities, but also because fish that present a number of ecosystem services are at risk, with consequences for biodiversity, ecosystem functioning, and ultimately human welfare. Examples are provided from marine and freshwater ecosystems in various parts of the world, and include all life-stages of fish.

Examples of regulation services

Compared to provisioning services, regulation services are more easily overlooked, but are of equal importance. Processes such as natural purification in wetlands and river ecosystems contribute to maintenance of clean water. The natural flow regime also supports other regulating ecosystem services, such as erosion, pollution, and flood and pest control. Riparian vegetation stabilizes river banks, but riparian vegetation is dependent on different flow regimes such as large floods for dispersal of seeds and fruits. The construction of dams stabilizes flows and captures sediment, thereby threatening many estuaries and coastal wetlands. The loss and degradation of freshwater ecosystems reduce the natural ability to buffer the impacts of floods and threaten the security of individuals and communities. Costanza & Farley (2007) describe how the loss of mangroves and other natural barriers played a key role in the devastating effects of Hurricane Katrina and the tsunami in southern Asia in December 2004. Coastal wetlands, marshes and islands in the Mississippi delta previously provided protection from storms but the sea has steadily eroded these features during the last decades, mainly because large dams in the Missouri and Mississippi Rivers have altered the flow regime and reduced sediment input to the delta. The presence of water also regulates the local climate and prevents dust. Almost 17 tons/hectare/year of dust polluted with pesticides are blown off the dried portions of the Aral Sea in Eastern Turkmenistan (O'Hara et al., 2000, Bennion et al., 2007). In the Sistan Inland Delta of Iran people suffer from both physical and mental health problems due to the hot dusty climate and the constant sandstorms that took place during a 7-year dry spell. When the wetlands were inundated, the same winds brought comfort in the form of refreshing water droplets blown over the villages (Meijer & Hajiamiri, 2007).

Cultural services, including sites of scenic beauty valued for recreation or sites for traditional ceremonies, are also important, although they are less tangible by comparison. In India, the flow of the River Ganges has an important place in Hindu mythology and river communities have a close link to the river. In the Sistan Inland Delta of Eastern Iran, the Hirmand River provides water to flood 500,000 ha of land, and establishes an oasis in a desert region and local people enjoy their New Year ceremonies along the shores of the wetland (Meijer & Hajiamiri, 2007).

Determination of environmental water needs – concepts and methods for the assessment of environmental flow requirements and how to provide guidance for policy implementation

Setting aside water to sustain various components in the ecosystem is nothing new. Tharme (2003) provides a thorough review of the over 200 different methods used to mitigate damage done by human degradation of freshwater systems. The methods used to assess environmental flows have over time developed from simple rule-of-thumb methods aimed to preserve commercially important fish species to holistic methods that encompass all important aspects of the ecosystem as well as socio-economic aspects. Even though many of the earlier methods, (e.g. the Tennant model; Tennant, 1976) were based on biological observations from a limited number of sites, the widespread use of these methods in other parts of the world has led to a lack of clear connections to ecological metrics and the values they were designed to protect. This led to the development of models that combine hydraulic ratings with ecological habitat metrics, with the most well-known developed by the U.S. Fish and Wildlife Service in the late 1970s (i.e. IFIM, the Instream Flow Incremental Methodology, Reiser *et al.*, 1989). However, a problem with these methods is that they are data intensive and thus relatively expensive to use. They also often focus on a very limited part of the ecosystem, typically commercially valuable fish. This limits their relevance to confined reaches of rivers and makes them difficult to apply in regions where ecological data are scarce. Holistic environmental flow methods encompass the whole range of flow variables and ecosystem components that need to be maintained, and additionally some (e.g. DRIFT –Downstream Response to Imposed Flow Transformation) focus also on sociological benefits of flow, such as maintenance of local freshwater and estuarine fisheries for subsistence uses (Arthington *et al.*, 2003; King *et al.*, 2003).

King & Brown (2006) describe how developing countries need to develop their water resources, societal benefits and economic gain. At the same time they face considerable international pressure to consider the full suite of environmental and social costs before decisions are made. Holistic environmental flow methods that provide a range of scenarios make it possible to evaluate trade-offs between development and environmental variables (Arthington & Pusey, 2003; King *et al.*, 2003). The holistic approaches typically employ panels of river scientists, managers and citizens who bring their collective knowledge of rivers into an agreed decision support framework, resulting in recommendations of environmental flow requirements (Cottingham *et al.*, 2002; Dyson *et al.*, 2003; Tharme, 2003; Arthington *et al.*, 2006; King & Brown, 2006; Richter *et al.*, 2006).

The concept of environmental flows lies within the hart of Integrated Water Resources Management (IWRM). IWRM is defined as *'a process, which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems'* (GWP TEC, 2000). In IWRM, there are three key strategic objectives:

- *Economic efficiency in water use*: Because of the increasing scarcity of water and financial resources, the finite and vulnerable nature of water as a resource, and the increasing demands upon it, water must be used with maximum possible efficiency;

- *Equity:* The basic rights for *all* people to have access to water of adequate quantity and quality for the sustenance of human well-being must be universally recognised;
- *Environmental and ecological sustainability:* The present use of the resource should be managed in a way that does not undermine the life-support system thereby compromising use by future generations.

Considering the literature statements above, the following future challenges arise in the context of the cross-cutting topic of ecosystem water requirements and environmental flows

2.6.1 Lack of knowledge about fresh water status

Dudgeon et al. 2005 discuss the knowledge gap when it comes to the status of freshwater biodiversity. There is no comprehensive global analysis of freshwater biodiversity comparable to those recently completed for terrestrial systems. They conclude that "existing data on the population status or extinction rates of freshwater biota are biased in terms of geography, habitat types and taxonomy; most populations and habitats in some regions have not been monitored at all". They also conclude that even a basic global mapping of inland waters, classified by broad geomorphic categories, is lacking – and there are no global estimates of changes in the extent of lakes, rivers or wetlands. Since then the Freshwater Ecoregions of the World project (Abell et al. 2008), produced by World Wide Fund for Nature and the Nature Conservancy, has synthesized biodiversity data for ecoregions (they define a freshwater ecoregion as a large area encompassing one or more freshwater systems that contains a distinct assemblage of natural freshwater communities and species). The data include richness and endemism numbers for freshwater fish, amphibians, turtles, and crocodiles. Distribution of freshwater species (primarily fish) and freshwater processes drove the map delineation. Another source for information about freshwater status is FishBase, which compiles fish data from around the globe (www.fishbase.org).

2.6.2 Lack of quantitative knowledge about flow-ecology links

Poff and Zimmermann (2009) carried out a substantial review (165 papers published over the last forty years) in an effort to see if it was possible to develop quantitative relationships between various kinds of flow alteration and ecological responses with existing knowledge. They concluded that existing data were not sufficient to develop general and transferable flow-ecology relationships and emphasized that "new sampling programs and analyses that target sites across well-defined gradients of flow alteration are needed to quantify ecological response and develop robust and general flow alteration–ecological response relationships. Similarly, the collection of pre- and post-alteration data for new water development programs would significantly add to our basic understanding of ecological responses to flow alteration". Groundwater resources are an important aspect of freshwater management, and also an important part of riverine ecosystems. Sophocleous (2007) identifies a number of knowledge gaps relating to ground water and its role in environmental flow assessments where hydrogeologists could contribute. These gaps specifically concern rudimentary knowledge about groundwater-dependent ecosystems, aspects of stream−aquifer interactions, and the impacts of land-use changes.

2.6.3 Lack of quantitative knowledge on the importance of freshwater ecosystem services for human livelihood

The definition of environmental flows given in the Brisbane Declaration (2007), highlights the human livelihood dimension of implementing environmental flows and the ecosystem services freshwater ecosystems provide. There is therefore a need to identify and recognise the various services, and find ways to value these services so that actors representing environmental water needs can effectively negotiate investments and trade-offs with other water users. Several methods do exist to do this but there is need for further research on to how to best mainstream such valuations into environmental flow assessments and water management decisions. Forslund et al. (2009) discuss the links between environmental flows and human livelihood in a Swedish Water House report entitled "Securing water for ecosystems and human well being; the importance of environmental flows".

2.6.4 Difficulty of implementation of environmental flows in water management

Despite the advances in the science of environmental flows, and the general consensus within the scientific community about the importance of environmental flows, implementation of environmental flow assessments within water management remains relatively scarce. Prior to the International Conference on Implementing Environmental Water Allocations in Port Elizabeth (South Africa) in February 2009, TNC, WWF, IUCN and the Global Environmental Flows Network (2009) held a workshop on the 'Nuts & Bolts of Flow Re-Allocation'. The conclusions of the workshop were that flow reallocation is unlikely to occur at the necessary scale without wider water governance reforms. Several institutional barriers to flow reallocation were identified, such as unclear property rights, high political and economic costs, and weak institutional capacity. Also existing legislation frameworks concerning water management may be a hindrance to implementation. The World Bank (Hariri and Davis, 2009) did a review of environmental flows in water resource policies, plans and projects and concluded that "environmental flow considerations need to be moved up to the more strategic levels of policy and basin plans to ensure that there is a strong basis for environmental water allocations". They also stressed the need for environmental flow considerations to be integrated with existing IWRM and environmental assessment processes. While the slow pace of implementation of environmental flows may not possess a gap in science per se it points to the need of a multi disciplinary approach, including social science, law and economics.

2.6.5 Valuation of ecosystem services – going beyond monetary valuation

Over the past decade, efforts to value and protect ecosystem services have been promoted by many to improve the recognition of the value of nature in environmental policy and decision making processes (Brauman et al, 2007; Daily, 2009). However, up-to-date no consistent methods for doing so exist even when progress has been achieved to improve methods for monetary valuation. Furthermore, putting monetary values on all ecosystem services is a contested approach. Arguments have been put forward for the need to develop alternative methods of valuation instead of putting monetary values to services that are not priced and not traded on the market. More efforts are required for developing conceptual and methodological approaches how valuation combining different methods could be achieved in a reproducible and consistent way. How to combine qualitative with quantitative and semi-quantitative approaches? How to combine analytical methods with participatory approaches? Suggestions have been made but little empirical evidence is yet available. A set of pilot-studies combined with systematic evaluation would be beneficial to build a sounder knowledge base.

Another important aspect is the need to develop integrative multi-scale approaches. Many monetary approaches work at quite aggregated scales and serve policy making at the national level. Analyses dealing with the importance of benefits for human livelihoods typically address the local scale. Trade-offs between different users and uses may vary from one level to another (Hein et al., 2006). Developing a multi-level approach and an integration of scales in space and time is thus an important issue. Finally, the different approaches to valuation need to be embedded in a wider understanding of environmental policy and resource governance.

2.6.6 Influence of governance regimes on environmental flows and ecosystem services

It is quite plausible to assume that the water governance regime is a major determinant for the trade-offs between different uses of ecosystem services and conflicts between users (e.g. Braumann et al, 2007; Pahl-Wostl, 2009). Understanding the current state and developing approaches for improvement requires a sound understanding of the role of governance regimes and how they affect environmental flows and ecosystem services.

This topic has up to now largely been ignored by the scientific community. This is clearly shown in the results of a bibliometric analysis of publications using the SCOPUS data base. Different combinations of key words were used to define “search terms”. The search results include the number of publications in peer reviewed journals in the search space “articles and reviews” that included the “search term” in the abstract, title or key words.

Search Term	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
"Environmental Flow"	16	17	24	17	40	22	45	47	43	70
"Ecosystem Service"	32	36	45	64	77	76	122	213	280	379
"Ecosystem Service" AND Water	9	15	15	22	22	26	43	60	90	107
Governance AND Water	12	18	36	19	39	59	58	86	106	135
"Environmental Flow" AND Governance	0	0	0	0	0	0	2	0	0	0
"Ecosystem Service" AND Water AND Governance	1	1	0	0	0	0	1	1	1	0

Table 2: number of publications regarding ecosystem water services and environmental flows in peer reviewed journals in the search space “articles and reviews” that included the “search term” in the abstract, title or key words

The interest in both water related ecosystem services and water governance has considerably increased over the past decade. Research combining the two is non-existent. It can be suspected that the major reason for this is that the thematic areas of governance and ecosystem services are analyzed by entirely separated scientific communities.

2.6.7 Implications of adaptation to climate change

Global and climate change will affect ecosystem services considerably. Studies have warned that risks and trade-off between services may increase (e.g. Alcamo et al, 2005). In contrast other authors have increasingly argued that emphasis should not only be on how climate and global change will affect ecosystem services but rather how investment in natural capital and ecosystem services can reduce the vulnerability to climate change by building adaptive capacity (e.g. Smith and Barchiesi, 2009). Well-functioning watersheds and intact floodplains and coasts provide water storage, flood control and coastal defence. They are ‘natural infrastructure’ for adaptation. Such a line of argument is also inherent in the paradigm shift in flood management from “Control of water” to “Living with water” (Pahl-Wostl, 2007).

Such changes in the overall framing imply that increasing and sustaining adaptive capacity of social-ecological systems become a major policy and management goal where a wide range ecosystem services are taken into account. Despite the increasing interest of these arguments, the scientific base is yet quite weak. How to support a transition to such a more holistic approach to water policy and management? Under which conditions would such a development be more likely than an increase in trade-offs between services and conflicts?

3 Conclusions and Outlook

The previous sections are a first attempt to comprehensively identify future research needs in relation to water management in the context of global change. Taking a closer look at the single chapters allows us to draw three main conclusions:

First, even though the main six cluster themes are not completely unexplored, there is still a large variety of topics with high research potential within the field of water management. For each of the six main cluster themes numerous knowledge gaps have been identified on the basis of literature and expert knowledge. While the investigation of some of these knowledge gaps might be feasible within the short-term, many themes will require far more time and human resources. Others again might not even be explorable at all within the next years, because investigations in a specific research field are not assumed to deliver satisfying results at reasonable levels of expenses.

Second, many of the research needs show high political relevance. Closing many of the knowledge gaps will only be possible if water research is developed and moulded – from the beginning on – to the needs of water policy-makers and practitioners. The policy-science-interface needs to be strengthened by continuous and active involvement of stakeholders such as water managers in the research processes. During the “Science to Policy Day” at the first International Conference on Adaptive and Integrative Water Management (CAIWA, November 2007 in Basel/Switzerland) it was emphasised that policy-makers and practitioners must increase their cooperation efforts in order to balance the differences in understanding present opportunities and to increase knowledge (Ridder, Pahl-Wostl 2007)[6]. The participants agreed that mechanisms are needed that allow linkages between the technical discourse and the political dialogue at multiple administrative levels and between multiple sectors. Moreover, it was highlighted that collaborative research and communication needs to become more specific in terms of solutions provided and actions recommended. Currently, the policy-oriented results by research are often too abstract for policy-makers to be translated into concrete actions. One means to achieve this could be to include policy-makers and practitioners more intensively into the design of applied

[6] D. Ridder, C. Pahl-Wostl, *Key messages of the CAIWA conference 2007*. NeWater Policy Brief No. 7. Available online at http://www.newater.info.

research. Another means is to take better notice of which data and information is really relevant to policy makers and practitioners.

Third and final, many of the research questions within the six main cluster themes show a high level of thematic interrelation. For example there are close inter-linkages between the social science perspective on adaptation to climate change, the questions on vulnerability and disasters and the issue of water governance in general. Within all three topics the institutional dimensions of water management have been identified as pivotal future research issues. It is by no means surprising that the authors refer to similar future research questions. Water management in the context of global change is a complex issue and research on this is not isolated. Some of the future research questions might be redundant; others simply reflect the different perspectives of a specific research need. Shedding new light on a future theme from the different perspectives will help to open up the interweavement of water management themes in the context of global change. Likewise it will allow us to cluster and synthesise the different themes in the next step.

Different tasks characterise the second period of the project. First of all a prioritisation of the research themes is needed in order to identify those knowledge gaps in water management in the context of global change that are most significant in terms of both their scientific relevance and their political impact. In line with this first task, a sound synopsis of all research questions is needed in order to reduce redundancies and gain best syntheses. Also the further development of future research topics must be considered: what are the requirements for a thorough investigation of the research themes and how to achieve best results in future projects of water management? On the basis of these tasks final recommendations will be developed for a future research programme of the BMBF.

To ensure a sound expert basis for further work a two-day expert workshop will be organised in February 2010 in Osnabrück. About 25 national and international experts of water research and management have been invited. The goal of the workshop is to discuss the main results of this milestone report, to cluster the different topics of the assessment and give joint recommendations for promising future research themes and their future requirements.

4 Annex: References (non-exclusive)

4.1 Section 2.1: Adaptation to Climate Change

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Water for Food in 21st century: Analysis of potentially new themes in water management - future trends and research needs

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1 Introduction

1.1 Relevance

The German Ministry of Education and Research (BMBF) has funded several major research programs on Integrated Water Resources Management and Global Change. Currently, BMBF is in the process to identify promising future research themes by analyzing the international water research and policy landscape and by taking stock of recent achievements.

Based on a preliminary assessment the following themes of high political relevance and major research needs and potential have been identified:

1. Adaptation to climate change
2. Food and water
3. Urbanization and infrastructure
4. Disasters and vulnerability to water related threats
5. Water governance (cross-cutting)
6. Ecosystem water requirements – environmental flows (cross-cutting)

This report contributes to theme 2 “Food and Water” and covers four so-called Application Areas:

- Development of a Global Water and Food Framework (PD/WI[1])
- Water and Food in Africa from a Global Perspective (NG)
- Water and Food in Big Cities from a Global Perspective (NG)
- Water and Food in South-East Asia from a Global Perspective (PD/WI)

Criteria used to describe the four Application Areas:

1. Gaps in scientific knowledge and potential to achieve scientific breakthroughs

- Expected outcomes have the potential to open up an internationally visible and innovative research field.
- Gaps in highly relevant fields with little indication of any large international program addressing them.
- Interdisciplinary approach needed to achieve scientific breakthroughs (preferably comprising collaboration between social and natural sciences)
- Barriers to be overcome are judged to be surmountable in a research programme

2. Science-policy interplay

- Link to relevant stakeholders, efficiency and effectiveness of implementation, potential of a programme to have a real impact
- Policy problem is tangible enough that a research program can provide meaningful policy advice within a limited time frame.
- International relevance but scope for German or European policy to play a leading role
- Ongoing - developing policy process to which the program can be linked

3. Relevance of international policy problem

- Policy problem is emergent, has been identified more recently and is currently moving higher on the policy agenda.
- Most likely to be persistent over the next decade and become even more urgent.

4. Suitability of the program to be implemented in the German scientific community

- Critical stock of available expertise in the German research community to address the issues
- Program has the potential to strengthen an emerging research community (e.g. water governance)
- Build in strengths and achievements in the German research community without duplication of previous programs
- Support of developing collaborations between communities that have failed to do so in the past.

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1.2 Trends in Food Demand

Food production will have to increase by 1-2% per year for the next generation in order to keep up with food demand. Increase in food demand is caused by a combination of population growth and changes in consumption patterns, especially an increase in animal-based protein in our diets (Liu & Savenije, 2008). The production of biofuels may, until the advent of so-called third generation biofuels, may put extra stress on grain and sugar production, although such stress will only be very localized (Hoogeveen et al., 2009). The spike in food prices in 2008 (see Figure 1) has dampened but food prices are still 70% higher than they were five years ago. It has been known for a long time that the supply elasticity of food is low. World trade without dramatic productivity rises can, therefore, only be a limited solution.

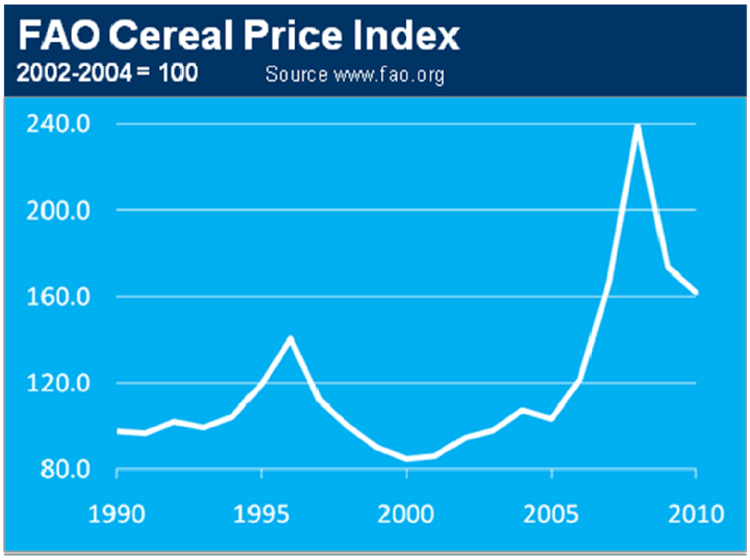

Figure 1. Commodity price development (source: FAO).

Various global assessment studies exist using an integrated approach to assess trends in food demand with a linkage to water. The approaches followed by these global studies can be divided into two groups. On the one hand studies exist that have a strong embedding in the economic science where physical (hydrological) processes are to a large extent ignored. In these studies water-food issues are represented by simplified parametric equations and the main driving forces are considered to be the economic ones. These economics are often based on food demand and food supply. Typical examples include the work of the International Food Policy Research Institute (IFPRI) in Washington.

The other group of global studies on water and food interactions is based on strong hydrological assessment. The economics are assumed of lower importance and often limited to a post-calculation of the agro-hydrological results rather than a driving force. Some typical examples include the work on the so-called AEZ (agro-ecological zones) of the The Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA). A more recent approach is the so-called LPJ-MAgPIE project (Lotze-Campen et al., 2005) based on the Lund-Potsdam-Jena Dynamic Global Vegetation-Model (LPJ) and the "Management model of Agricultural Production and its Impact on the Environment" (MAgPIE) models were coupled. A prototype has been developed for Germany as well (Lotze-Campe et al., 2008).

One common weakness in both approaches is the focus on average conditions. There are hardly any global studies that include the natural year-to-year variation in the analysis, while it is expected that the impact of climate change will alter not only the mean but will have a significant increase on extremes.

An interesting synthesis paper was published recently looking at the global perspective of water and energy inputs in food production (Khan and Hanjra, 2008). The main findings in this review are repeated here:

- Loss of natural habitat on agriculturally usable land (Green et al., 2005).
- Increase in continental water storage formerly flowing to deltas, wetland and inland sinks and its impacts on greenhouse gases (Milly et al., 2003).
- Homogenization of regionally distinct environmental templates/ landscapes, due to excessive construction of dams (Poff et al., 2007), thereby altering natural dynamics in ecologically important flows on continental (Fig. 2) to global scale (Arthington et al., 2006).
- Loss or extinction of freshwater fauna populations and habitat for native fisheries, plummeting population of birds due to inadequate water flows, and loss of riverine biodiversity due to large scale hydrological changes in tropical regions (Dudgeon, 2000).
- Biodiversity loss associated with agricultural intensification (Butler et al., 2007; Kremen et al., 2002).
- Enhanced global movement of various forms of nitrogen between the living world and the soil, water, and atmosphere with serious and long-term environmental consequences for large regions of the Earth (Vitousek et al., 1997).
- Nitrate pollution of agricultural landscapes and groundwater resources, and nitrogen- and phosphorous-driven eutrophication of terrestrial, freshwater, and near-shore marine ecosystems, causing unprecedented ecosystem simplification, loss of ecosystem services, species extinctions, outbreaks of nuisance species, shifts in the structure of food chains, and contribution to atmospheric accumulation of greenhouse gases (Correll, 1998; Tilman et al., 2001).
- Synthetic chemicals compromising symbiotic nitrogen fixation, thus increasing dependence on synthetic agrochemicals and unsustainable long-term crop yields (Fox et al., 2007).
- Soil salinity and water logging and impaired natural drainage, and associated damages to infrastructure and lost opportunities for regional growth and economic development (Khan et al., 2006; Kijne, 2006; Wichelns and Oster, 2006).
- Depletion of groundwater aquifer and reduced stream flows (Khan et al., 2008a) and associated impacts on drinking water supplies, health and rural livelihoods (Meijer et al., 2006). Displacement of population due to dam construction (Cernea, 2003), and higher incidence of vector-borne diseases in some irrigation areas and loss of human productivity (Lautze et al., 2007).
- Reduced capacity of the ecosystems to sustain food production, maintain freshwater and forest resources, purify water, regulate climate and air quality, or ameliorate infectious diseases (Foley et al., 2005).
- Global accelerated erosion from plowed agricultural fields and hill slope production – greater than 1–2 orders of magnitude than rates of soil production; and erosion under native vegetation, and long-term geological erosion (Montgomery, 2007).
- Erosion caused by human transport of larger amounts of sediment and rocks for construction and agricultural activities exceeding all other natural process operating on the surface of the planet (Wilkinson and Mcelroy, 2007).
- Surge in extreme hydrological events such as storms, droughts and floods (Illangasekare et al., 2006).
- Global, inter- and intra-state conflict over freshwater resources and potential for social instability (Yoffe et al., 2004).
- Raised threat level of global terrorism to water resources due to elevated risk to dams and reservoirs (Gleick, 2006; Mustafa, 2005).

These points mentioned by Khan and Hanjra (2008) can be considered as a starting point when identifying research priorities related to food and water in the context of global change. Another important report that provides a baseline for food production projections is the “Agriculture towards 2015/2030” report by the FAO. This report is based on the converging opinions of food and agricultural experts. The report has a conservative outlook in the sense that it uses low estimates for productivity increases, etc, and also does not take climate change into account.

Important conclusions of this study are that most of the population increase to 9 billion people in 2050 will take place in the developing world. Only 16% of the world food production finds its way into the international trade system, which means that most extra food will most likely to have to be grown in the developing world. Lifestyle changes will increase the average food supply to rise from 2650 Kcal/person/day in 2006 to 3000 Kcal/person/day in 2050. This implies that total aggregated agricultural production will need to increase by 2050 with 70% with respect to production levels in 2006.

The sources of production growth will come from expansion of arable land, increase in cropping intensity, and increase in yields. Yield increase estimates are modest at around 0.7% per year for the major grains as opposed to the 2.0% annual growth that was observed over the period 1961-2007.

Extra food production will be achieved differently in different places. In South and East Asia, intensification and additional irrigation will be important, whereas the food production increase in Africa and Latin America will mainly be achieved by extending the surface of arable land. Water will play an important role. The Middle East and North Africa are particularly under stress, both from a land and from a water point of view. Presently, 43% of total agricultural production in the world is produced on the 23% of the arable land that is being irrigated. The annual growth rate for irrigated area is estimated at around 0.7% for Africa and Latin America and at around 0.15% and 0.3 % for South and East Asia, respectively. The irrigation potential for Africa and Latin America will remain large compared to the irrigated areas, whereas in East Asia and in the Near East and North Africa, the total irrigated area approaches the total irrigation potential.

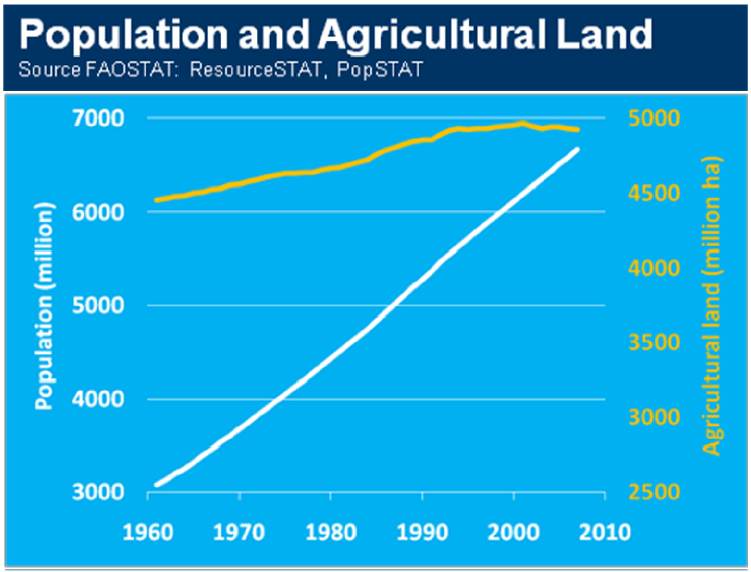

Figure 2. Global population growth and development of agricultural land (source: FAO).

1.3 Proposed Global Perspective Water-Food

From the previous sections it is clear that global food production will have to increase and that water will be one of the main constraints to achieve this. At the same time other stressors like climate change, bio-fuels, improper management, global trade, and land grab will amplify, or at least increase uncertainty, about future water-food linkages.

Various global water-food analyses have been initiated over the last decade, but in most cases these analyses are somewhat biased towards one discipline. There is a big need to have a framework that integrates all aspects of water-food: physics, economics, management, social aspects, land and trade.

The global water-food framework as proposed here includes four components, referred to as Application Areas: (i) development of a global water and food framework, (ii) Africa, (iii) big cities, and (iv) Asia. These Application Areas were selected based on a previous document (Droogers and Giesen, 2009) and a scoping workshop (Osnabrück, Germany; 2/4-Feb-2010). The main outputs of the workshop with respect to the food and water theme are summarized here.

1.3.1 Development of a Global Water and Food Framework

An integrated public domain global water and food framework will be developed that enables to undertake scenario analysis with a strong emphasis on climate change. The framework will include physical aspects (water resources, land, climate), economics (food and land prices, global trade), management (water abstractions, efficiencies), and social aspects (water rights, poverty).The framework (data, models, scenarios, output) will be setup in a completely open source, Wiki-type environment, to ensure wider dissemination, quality control, and data and knowledge exchange.

1.3.2 Water and Food in Africa from a Global Perspective

The global framework to be developed requires a strong emphasis on Africa, where the most potentials but at the same time the biggest threats to food and water security occur now and in the future. The framework for Africa will be developed simultaneously with the global model but specific emphasis will be put on the economics of extensive foreign investments in land, closing yield-gaps and management aspects.

1.3.3 Water and Food in Big Cities from a Global Perspective

Big cities are largely ignored in current global water-food studies. However, urban agriculture, waste water irrigation, urban livestock, domestic water competition and food trade are key in global water-food analysis. For a few mega-cities these aspects will be studied and included in the global water and food framework. Based on these pilot cities all big cities will be implemented in the framework. Scenario analysis will indicate in which direction water-food issues will develop and what decisions could be taken for sustainable development.

1.3.4 Water and Food in Asia from a Global Perspective

Water and food interrelationships are extremely high in Asia. High population concentrations, large dependency on erratic rainfall, huge irrigation schemes, vulnerable to sea-level rise, and complex water competition issues make the area extremely important from a global as well as regional perspective. The region will be studied in a multi-disciplinary way, with a strong focus on risk and vulnerability issues. The study will be developed simultaneously with the global water-food framework to ensure linkages between and within the region and the global scale.

2 Development of a Global Water and Food Framework

Workshop "Future trends and research needs in water management"; 2nd to 4th February 2010 Osnabrück, Germany

Development of a Global Water and Food Framework

An integrated public domain global water and food framework will be developed that enables to undertake scenario analysis with a strong emphasis on climate change. The framework will include physical aspects (water resources, land, climate), economics (food and land prices, global trade), management (water abstractions, efficiencies), and social aspects (water rights, poverty). The framework (data, models, scenarios, output) will be setup in a completely open source, Wiki-type environment, to ensure wider dissemination, quality control, and data and knowledge exchange.

Major Conclusions

Gaps in scientific knowledge

- At the global scale existing global frameworks such as the green and blue water framework could be improved by including management and adaptation options.
- There is a need for global crop water models that can quantify the demand and supply side of agricultural water at a large scale with sufficient physical detail.
- User-friendly decision support tools such as water allocation and planning tools and serious gaming tools are required to get the message across to decision makers.
- A dedicated data-portal that integrates public domain datasets on the interface of climate, hydrology, agriculture and socio-economics is in great demand.
- Basic datasets on water consumption and water productivity are largely lacking.

Science-policy interplay

- Food production will have to increase by 1-2% per year for the next generation in order to keep up with food demand.
- Improved technologies, innovation and policy shifts can achieve this required increase in agricultural productivity but research is of crucial importance.

Relevance of international policy problem

- The direct links with climate change, the tradeoff between food and bio-fuel production, the global economy and the increasing population has put the topic high on all international agendas.

German Scientific community

- German scientists from various universities have contributed significantly to the development of global models and datasets and already have a specific niche in this area.

2.1 Gaps in scientific knowledge and potential to achieve scientific breakthroughs

Over the last three years two comprehensive global state-of-the-art studies on water and food have been presented. The first one, Comprehensive Assessment of Water Management in Agriculture (Molden, 2007) describes in 16 chapters the state of the art of water and food: *"The Comprehensive Assessment of Water Management in Agriculture critically evaluates the benefits, costs, and impacts of the past 50 years of water development, the water management challenges communities are facing today, and solutions people have developed. The results will enable better investment and management decisions in water and agriculture in the near future and over the next 50 years. The assessment is produced by a broad partnership of practitioners, researchers and policy makers."*

The main message of this comprehensive assessment is that if appropriate measures, including research, will be taken, food security can be achieved under current and future conditions. The analysis resulted in eight so-called policy actions, which have implications for setting the research agenda (Molden, 2007):

- 1 Change the way we think about water and agriculture
- 2 Fight poverty by improving access to agricultural water and its use
- 3 Manage agriculture to enhance ecosystem services
- 4 Increase the productivity of water
- 5 Upgrade rainfed systems—a little water can go a long way
- 6 Adapt yesterday's irrigation to tomorrow's needs
- 7 Reform the reform process—targeting state institutions
- 8 Deal with tradeoffs and make difficult choices

The second comprehensive studies on global water and food issues are undertaken by the UNESCO World Water Assessment Programme (WWAP, 2009 and WWAP, 2006). The key messages as described in the World Water Development Report (WWAP, 2006) are:

- To satisfy the growing demand for food between 2000 and 2030, production of food crops in developing countries is projected to increase by 67 percent.
- As competition for water increases among different sectors, irrigated agriculture needs to be carefully examined.
- Farmers are at the centre of any process of change and need to be encouraged and guided.
- Irrigation institutions must respond to the needs of farmers, ensuring more reliable delivery of water, increasing transparency in its management and balancing efficiency and equity in access to water.
- The agriculture sector faces a complex challenge: producing more food of better quality while using less water per unit of output.
- Action is needed now to adapt agricultural and rural development policies.

The key messages of the latest report, WWDR-2009, are summarized as:

- Population growth and rapid economic development have led to accelerated freshwater withdrawals.
- Trends in access to domestic water supply indicate substantial improvement in the past decade.
- Steadily increasing demand for agricultural products to satisfy the needs of a growing population continues to be the main driver behind water use.
- The recent acceleration in the production of biofuels and the impacts of climate change bring new challenges and add to the pressures on land and water resources.

- Freshwater ecosystems provide an extensive array of vital services to support human well-being.

This latest report of the WWAP included an interesting section on “How much do we know about water uses?” The report provides the following view on this:
“Our knowledge of water use is as poor as our knowledge of water resources – perhaps poorer. Information is largely incomplete – particularly for agriculture, the largest user – and is lacking altogether for some countries. Only limited disaggregated information exists, and even this shows deficiencies of validity and homogeneity and provides extremely poor information on trends. The quality of information systems varies with each country, but there are common difficulties:

- *Statistics on the magnitude of demand and withdrawal are often estimated rather than based on data that are measured or collected from censuses. The level of uncertainty varies, but is particularly high for agriculture.*
- *Sectors of use are not defined homogeneously and are not well disaggregated.*
- *Adequate historical datasets are rare, and the dates of available statistics are not always explicit.*
- *Lack of agreed terminology leads to discrepancies in data compilation and analyses”*

Characteristics of both state-of-the-art studies are that substantial human (over 1000 contributors) and financial (over few million dollars) resources have contributed to the success and acceptance of the main findings. The studies have therefore a significant impact on science policy setting and set the scene for any additional global work in the area of water and food.

In order to implement the recommendations and research agendas set out by these comprehensive studies a framework is proposed that integrates physical and socio-economic aspects and covers the entire spectrum from data expert-knowledge, models and strategic decision support systems. The following key scientific gaps can be distinguished:

Conceptual frameworks

There is a need for the development of new conceptual framework that should be used to guide the global water-food and climate change progress. In a recent special issue of the Journal of Hydrology devoted to the green blue water initiative (GBI) some key concept are discussed that could be used as a starting point for further development (Hoff, 2010). The authors describe a concerted effort to quantify at global scale, geographically explicit and process-based, the full green and blue water resource, integrating water and land management. The distinction between green and blue water is a strong concept and analysis shows that globally, green water use by crops is about 4–5 times larger than consumptive blue water use (Hoff et al., 2010). Further improvements of the framework could focus on further inclusion of management and adaptation options such as such as rainwater harvesting, small scale storage, supplementary irrigation, improved irrigation and fertilization, as well as expansion of agricultural land, virtual water trade and investments in agricultural water management have been quantified by the different models.

Global models and decision support systems

At the global scale there is a need for models and tools that can be used to analyze the interaction between crop water demand and use and water availability at the scale of large river basins. Several global models exist and further developments should build on these efforts. A good example specifically aimed at quantifying green and blue water and virtual water flows is the global crop water model (GWCM) developed by Siebert and Doll (2010). GWCM computes consumptive water use (evapotranspiration) and virtual water content (evapotranspiration per harvested biomass) of crops at a spatial resolution of 5′ by 5′, distinguishing 26 crop classes, and blue versus green water. Besides further developments of global scale hydrological models emphasis should be put on strategic decision support systems. To get the complex message across there is a need for user-friendly tools that enable decision makers to efficiently visualize and assess the impact of possible intervention techniques. In this respect focus should be on water allocation tools such as the Water Evaluation and Planning (WEAP) tool developed at the Stockholm Environment Institute. De Condappa et al (2009) applied this tool for example in the Volta basin. Serious gaming is another emerging field that should be taken into account.

Global water-food-climate datasets

Huge amounts of public domain datasets are available nowadays, but there is a need to integrate and standardize these data for application in water-food-climate studies. Remote sensing could play a major role here as more and more remote sensing data becomes publicly available. A dedicated data portal for water-food-climate studies should be developed that integrates climate (change) data, physical conditions (land use, soil), water consumption by agriculture, reservoirs from a variety of sources. A key gap in data availability is a consistent real time dataset of consumptive use of water by agriculture (evapotranspiration). Algorithms are available that derive evapotranspiration and water productivity from satellites (Zwart et al., 2010) but more work is required in this field. In addition there is a great need for gauge corrected precipitation datasets.

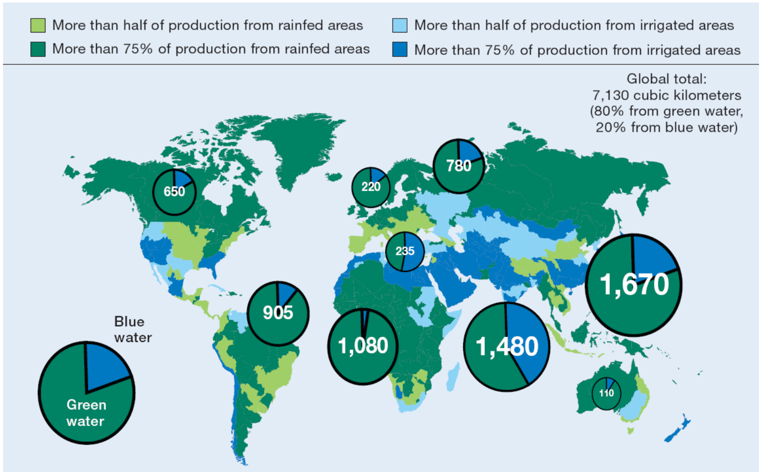

Figure 3. Food crop evapotranspiration from rain and irrigation (source Molden, 2007).

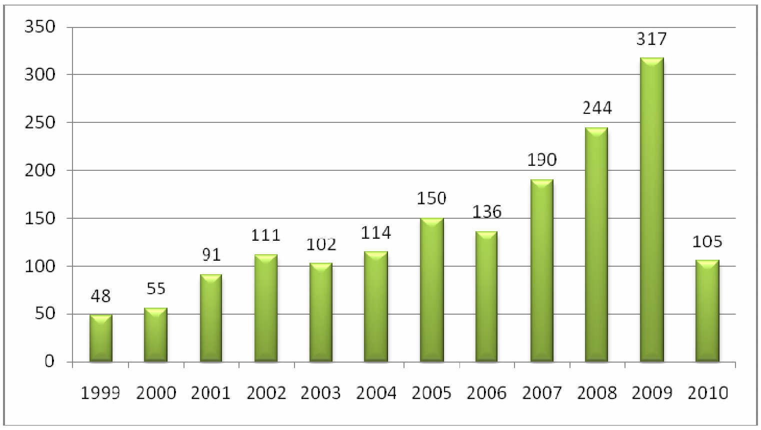

Figure 4. Number of publications (Scopus) using search words: water+food+climate

2.2 Science-policy interplay

The science-policy interplay on water and food can be considered as very high. In fact the first global assessment on food supply and demand was published by Thomas Robert Malthus in 1798, who famously predicted that short-term gains in living standards would inevitably be undermined as human population growth outstripped food production. However, the more recent scenario studies at the global level indicate that applying innovative methods and policies the potential of agriculture is large enough to meet present and future food demand through increased productivity (Molden, 2007). An optimistic rainfed scenario for example assumes significant progress in upgrading rainfed systems while relying on minimal increases in irrigated production, by reaching 80% of the maximum obtainable yield. This leads to an average increase of yields from 2.7 metric tons per hectare in 2000 to 4.5 in 2050 (1% annual growth). With no expansion of irrigated area, the total cropped area would have to increase by only 7%, compared with 24% from 1961 to 2000, to keep pace with rising demand for agricultural commodities. The same study indicated also that focusing only on rainfed areas carries considerable risks. If adoption rates of improved technologies are low and rainfed yield improvements do not materialize, the expansion in rainfed cropped area required to meet rising food demand would be around 53% by 2050. Globally, the land for this is available, but agriculture would then encroach on marginally suitable lands and add to environmental degradation, with more natural ecosystems converted to agriculture (Molden, 2007).

In contrast to this optimistic few, Rost et al. (2009) presented, what they claim, one of the first studies focusing on a spatially explicit quantification of water limitations in global crop production and the potential of different water management strategies to upgrade crop growth, under both present and projected future climate conditions. The study indicated that even the most ambitious and large-scale water management efforts on present cropland will not be sufficient to guarantee the food demands of a growing world population. This result is quite in contrast with most other studies (Molden, 2007; WWDR, 2006; WWDR, 2009; Rosegrant et al., 2009). A nice overview of these global assessments studies was published in Science by Rosegrant and Cline (2003).

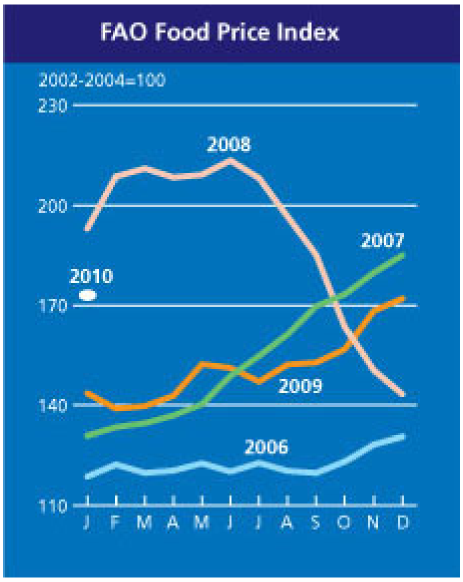

Figure 5. Food Price Index. Source: FAO, 2009.

2.3 Relevance of international policy problem

There is sufficient evident that the issue of food security and the linkage to water is an emergent policy problem and is currently moving higher on the policy agenda. The issue will be most likely persistent over the next decade and become even more urgent. This is in still contrast to the expectations of over a decade ago, when food prices dropped and food security appeared to be more a sharing problem rather than a shortage problem.

However, after decades of improvements, the number of undernourished people (in millions) in the world has been rising rapidly since the mid 1990s (FAO, 2010). Development aid has seen an interesting trend. In the wake of the global food crisis of 1973–75, large investments in the agriculture sector (including for scientific research, rural roads and irrigation) led to rapid growth in cereal yields and lower cereal prices that, in turn, significantly reduced food insecurity. During those decades, the proportion of official development assistance (ODA, i.e. development aid contributed by donor governments) devoted to agriculture was also relatively high. During the 1990s and the current decade, however, the number of undernourished has risen, despite the benefit of slower population growth, and the proportion of undernourished increased in 2008 (Figure 6). In the same period, the proportion of ODA devoted to agriculture declined substantially; in 2007, after adjusting for inflation, the level of ODA was 37 percent lower than in 1988.

The FAO report “The State of Food Insecurity in the World: Economic crises – impacts and lessons learned” provides an convincing statement on the relevance of water and food on the international policy problem (FAO, 2009). The fact that hunger was increasing even before the food and economic crises, suggests that present solutions are insufficient. To eradicate food insecurity improved governance at the international, national and local levels are essential.

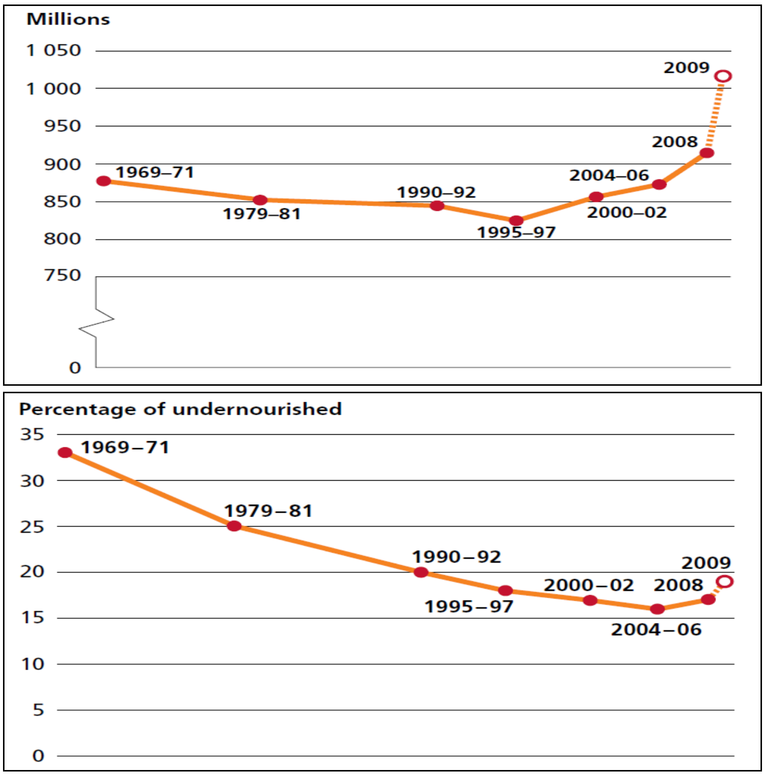

Figure 6. Number of undernourished in the world. Absolute numbers (top) and percentage of global population (bottom). Source: FAO, 2009.

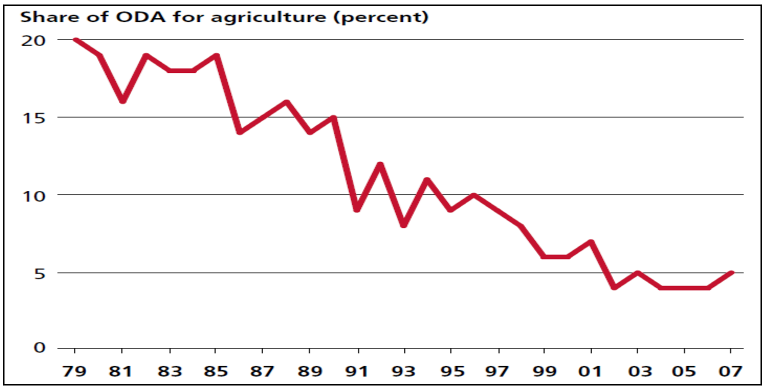

Figure 7. Official Development Assistance (ODA) as share for agriculture.

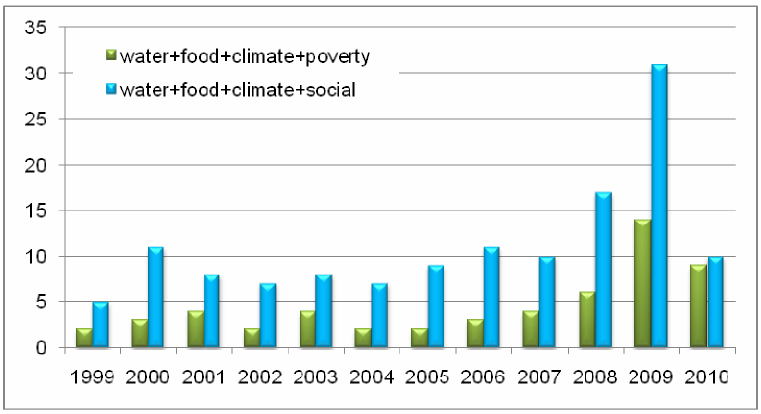

Figure 8. Number of publications (Scopus) using search terms as indicated.

2.4 Suitability of the program to be implemented in the German scientific community

There is great potential for the German scientific community as German scientists have contributed considerably in the development of a global water-food-climate framework. One of the first to be active in this field is the University of Kassel with their WaterGap approach (Alcomo et al., 2003; Döll et al., 2003). At the institute for physical geography of the University of Frankfurt a number of scientists are very active in this field as well. A global crop water model (Siebert and Doll, 2010), a global data set of monthly irrigated and rainfed crop areas (MIRCA) was developed (Portmann, 2010) and a global dataset with irrigated areas (Siebert et al, 2002). The work at the Potsdam Institute for Climate Impact Research is also relevant (Lotze-Campen et al., 2005) and on the interface of global food demand, productivity growth and the scarcity of land and water resources. Recently, the Potsdam Institute for Climate Impact Research has also started an emerging program on global water-food analysis using quantitative tools (Hoff, 2010).

3 Water and Food in Africa from a Global Perspective

Workshop "Future trends and research needs in water management"; 2nd to 4th February 2010 Osnabrück, Germany

Water and Food in Africa from a Global Perspective

The global framework to be developed requires a strong emphasis on Africa, where the most potentials but at the same time the biggest threats to food and water security occur now and in the future. The framework for Africa will be developed simultaneously with the global model but specific emphasis will be put on the economics of extensive foreign investments in land, closing yield-gaps and management aspects.

Main conclusions:

- Africa holds important potential for global food production by 2050
- Water is a limiting production factor, mainly due to unreliability of rains
- Large scale irrigation development is unlikely to take off soon
- Localized water harvesting strategies are needed
- A detailed predictive model is needed to assess the potential of different water harvesting techniques at sub-country level that takes landscape position into account
- The German research community is in a good position to contribute to this topic.

3.1 Link Global Perspective to food production in Africa: Relevance of international problem

The importance of Africa for global food production concerns two issues. First, food production in Africa has not kept pace with the global increase in agricultural productivity. Africa remains a net-importer of food and malnourishment on the continent is an important international concern.

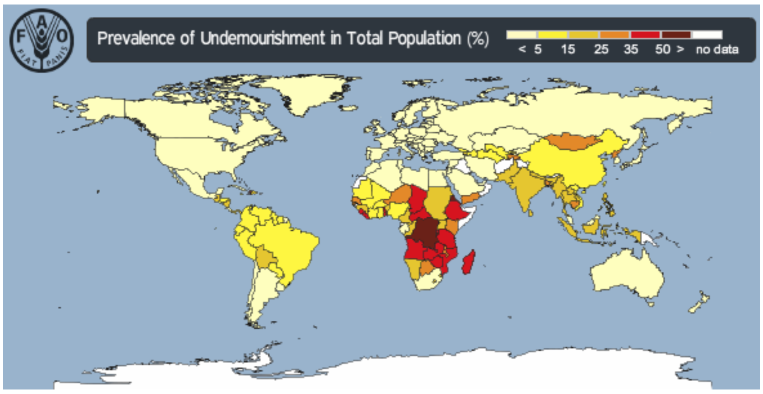

Figure 9. Distribution malnourishment. Source: fao.org/hunger

As can be seen from the figure, malnourishment is very prominent throughout Africa be it that the more severe cases are often directly linked to conflict and not necessarily to droughts or other agricultural limitations. The willingness of the international community to provide food aid is large but tends to have negative effects on the competiveness of African farmers. Africa, it seems, has sufficient agricultural resources to feed itself.

'If agriculture has a final frontier, it is Africa. After agriculture transformations in Asia and Latin America since the 1960s, Africa remains the one place where the farming potential has barely been scratched. African agriculture has less irrigation, less fertilizer use, less soil and seed research, less mechanization, less rural financing, fewer paved farm-to-market roads than any other farming region in the world.'

Roger Thurow, Wall Street Journal, 27 May 2008

From a global perspective it is interesting to note that Africa holds significant promise with respect to raising world food production. Most of Asia is under stress and the slight decrease in agricultural land over the past decade is mainly due to Asian urbanization edging out agriculture. Agricultural expansion in Latin America tends to come at the cost of important biodiversity strongholds such as Amazonia and the Pantanal. Eastern Europe and Central Asia have potential but the issues here are mainly institutional. Africa seems to be the most obvious place to significantly boost international food production. Experts agree that the main way to expand Africa's food production is through taking more land into production. (Hoogeveen et al., in preparation). Only where population pressure is high, such as in Machakos, Kenya or the Mosi Plateau in Burkina Faso, does intensification of agriculture, such as through irrigation, become feasible.

3.2 Gaps in scientific knowledge

The scientific literature on water and food production in Africa is dominated by the so-called "green&blue water" discussion (Hoff, 2010). "Green" water is water that is held under tension in the upper parts of the pedosphere that, from a practical point of view, can only be accessed productively by plants. "Blue" water is water under zero or positive pressure that can be pumped up and stored (groundwater, lakes, rivers). It is widely recognized that >95% of the food produced in Africa is grown under rainfed conditions (Alcamo et al., 2007). This stands in contrast to Asia, where the green revolution depended for a large part on the development and intensification of large scale irrigation infrastructure.

Water is clearly a limiting production factor in Africa but its exact role is not always clear in a complex production system where nutrients, labor availability, and access to market and cash also play important roles. The lack of reliability in rainfall patterns greatly reduces the expected returns on investments in agro-chemicals, seeds, and soil management. See, for example, Sultan et al. (2005) for an interesting study for West Africa of the role of in-season dry spells on crop productivity. The question then becomes how temporary water scarcity can be overcome.

Opinions differ on the exact role that irrigation may play in Africa. Based on FAO figures, it is estimated that the irrigated surface in sub-Saharan Africa will have to increase with over 50% by 2050, but the total will still be a mere 7 million hectares of the 377 million hectares world wide (Hoogeveen et al., in preparation). Total irrigation potential is estimated at 40 million hectares. Water productivity in irrigated schemes in Africa tends to be relatively low (Faulkner et al., 2008). There are several reasons why irrigation development in Africa lags behind Asia and other parts of the world. First, there are simply not many large alluvial plains fed by large rivers. Second, state-based governance is weak, reducing the chances at large scale irrigation development. Finally, infrastructure costs are relatively high due to lack of both human resources as well as supporting infrastructure. It is unlikely that there will be a fast turn-around and that irrigation in sub-Saharan Africa will really take off in the near future.

The only alternative is to increase the productivity of “green water”. Until now, most of these studies are at a macro level and do not take local specifics into account. The latter are needed in order to move from generic ideas to policies and investments. There are literally thousands of localized detailed agronomic studies concerning water of a specific crop on a specific soil in a specific management setting, etc. There are, however, no synthesizing studies that bring together this substantial knowledge base and translate it into regionalized insights in production potentials and water management options.

The main missing link in our knowledge is that between the large scale models and general observations and the detailed localized agronomic knowledge.

In this context, the agronomic knowledge should be interpreted as broadly as possible and should not only include all biotic and a-biotic resources but also the socio-economic context. Especially the role of markets and labor productivity are important in this respect.

From the present perspective it is probably more important to note that hydrological process knowledge is still lacking to improve water harvesting techniques. There are many ways in which water can be harvested and green water productivity can be improved. A very narrow definition of water harvesting, limiting this technique to pure in situ water use, (Hoff et al., 2010), is probably too exclusive. When water is temporarily stored on-farm in small reservoirs or underground, this can still be an important part of improving green water productivity (Savenije, 2000). The more important criteria would be investment costs and “light” governance.

Hydrological process knowledge is essential to target the correct technique for the correct region and for the correct landscape position (Winmeijer & Andriesse, 1993). For example, interception is normally an important part of the water balance in semi-arid environments but has received little scientific attention (de Groen & Savenije, 2006). Improving in situ water would have to address interception, as well as other often neglected losses such as unproductive soil evaporation. The potential of collecting surface water depends largely on slope, rainstorm and soil surface characteristics, yet we do not have the necessary information to map out what can be done where (van de Giesen et al., 2004). In parallel to the global modeling effort, a more detailed effort is needed for Africa in order to be able to assess the real potential of green water and water harvesting.

The literature count did not show any specific trends on sub-topics such as “Africa + Irrigation”. Perhaps the main conclusion is that the overall count is relatively low given the importance of the topic, thereby indicating that there is still ample room for more scientific output.

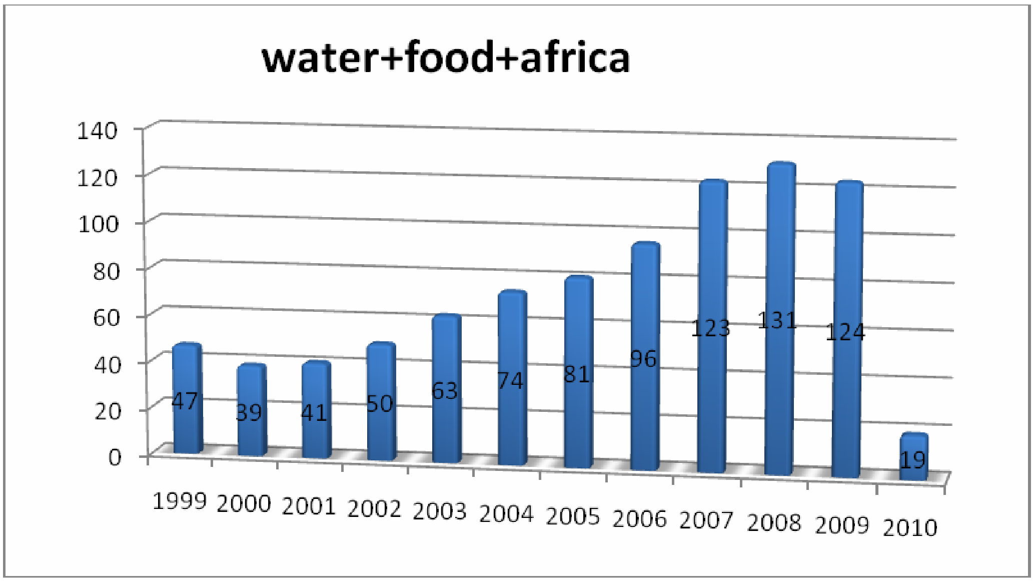

Figure 10. Number of publications (Scopus) using search terms as indicated.

3.3 Role of scientific research in support of policy

Investments will need to be made to boost Africa's food production. There are major international initiatives, such as IFAD's "Advancing African Agriculture", which mainly focus on traditional agronomical solutions. The role of water receives generally little attention, with the important exception of the Challenge Program Water for Food of the CGIAR. Even a substantial research investment by BMBF would not solve Africa's food production problems over night but this particular niche would have relatively good leverage.

The international community is trying to build a "Green Revolution for Africa". The original Green Revolution in Asia was to an important extent based on a parallel "Blue Revolution" consisting of massive investments in irrigation infrastructure. In Africa, such a "Blue Revolution" is needed as well but will most likely not take the form of massive irrigation investments. A one-size-fits-all water management approach can not be expected to yield good results.

National governments, international programs, donors (Germany, EU, WB, …) would profit from regionalized knowledge on optimal water management options. Such research would help agencies to answer the following question:

- **Where is large scale irrigation development feasible?**
- **Where is supplementary irrigation feasible (design & economics)?**
- **Where are field level measures preferred and what form should they take?**

The current generation of relatively coarse and global models will not be sufficient because they can not go beyond generalities.

3.4 Role of German research

Germany has extensive experience with respect to agronomical research throughout Africa, for example through GTZ sponsored programs. The strong involvement over the years in Africa by DAAD is reflected in its programs in, among others, Stuttgart, Bonn, Hohenheim, and

Goettingen. This research experience provides the basis of the localized knowledge that is needed to improve water productivity in Africa. What is needed is to contextualize the existing knowledge in the framework of continental scale integrated modeling.

Germany is host to the Global Water System Project, which has strong ties with the water (productivity) modeling community. There are strong global modeling groups (Alcamo, Doell) that can provide the large scale methodologies, data management techniques, etc.
BMBF's GLOWA Program, with especially the Impetus & GLOWA Volta projects, has produced a generation of young German scientists who have first hand insight in water and food in Africa. There is also ample experience with integrated approaches from other projects, such as CuveWater at ISOE, and BIOTA. Overall, Germany has the integrative research experience needed to perform the proposed research.

A BMBF program/project on water and food in Africa would (should) bring together these different communities.

4 Water and Food in Big Cities from a Global Perspective

Workshop "Future trends and research needs in water management"; 2nd to 4th February 2010 Osnabrück, Germany

Water and Food in Big Cities from a Global Perspective

Big cities are by enlarge ignored in current global water-food studies. However, urban agriculture, waste water irrigation, urban livestock, domestic water competition and food trade are key in global water-food analysis. For a few mega-cities these aspects will be studied and included in the global water and food framework. Based on these pilot cities all big cities will be implemented in the framework. Scenario analysis will indicate in which direction water-food issues will develop and what decisions could be taken for sustainable development.

Main conclusions

- **Given the continuing urbanization, the extractive nature of the city economy in terms of water, food and energy, needs to be changed.**
- **The theme "Water and Food in Urban Areas" can only be addressed meaningfully in the broader framework of the complete water-food-energy nexus.**
- **Transition management will have to be an important research theme.**

This chapter is for an important part based on the earlier report by Engelbert Schramm, Rutger de Graaf and Thomas Kluge produced for the February workshop.

4.1 Link Global Perspective to Water and Food in Urban Areas

Since October 2008, more than 50% of the world population lives in cities and this percentage will continue to increase for the next 50 years. Already in 2030, the global urban population will be over 5 billion. As a collateral development, the global rural population will decrease from 2020 onwards. The traditional asymmetrical relation between urban and rural areas may have to be revised thoroughly.

Some of the oldest existing irrigation systems are urban systems (Sanaa, Jericho, Aleppo). However, in the present socio-economic setting, food production in urban areas is seen as marginal at best (peri-urban agricultural). At the same time, we see a certain industrialization of agricultural and, especially, horticultural production that could easily be accommodated in an urban setting. Still, the theme water and food in cities would most productively be addressed if seen in the context of the urban hydrological cycle (including drinking water and waste water) and energy production and distribution (heat/cold storage, solar energy collection, evaporative cooling).

The global water-food-energy nexus is especially complex in urbanized areas. From a water perspective, cities have parasitic relation to the surrounding rural areas. Drinking water is extracted from outside and, once polluted, dumped outside. Energy production does not typically take place within cities and results in extra pressures on water resources (reservoirs, heating). A transition is needed in which cities will take more care of their own water, energy and food.

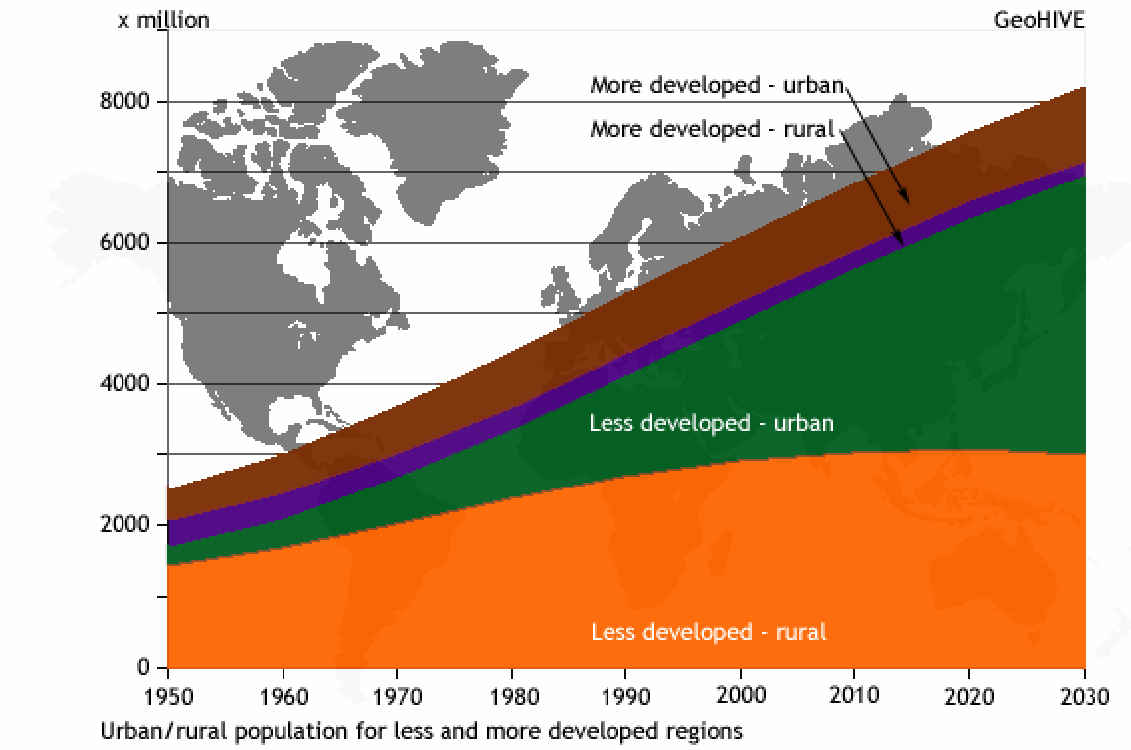

Figure 11. Development of urbanization. Source: geohive.com, referenced to Population Division, UN: World Population Prospects: The 2004 Revision and World Urbanization Prospects: The 2003 Revision.

From a technical point of view, it is possible to analyze the town-hinterland relations in order to find out what kind of ecological backpack is brought into town along with food and what kind of dependencies exist between a town and the water supplies of its hinterland. In a similar way virtual water could be taken into consideration in order to examine where successful water saving is sabotaged by externalising production steps.

Since the 19^{th} century, there has been a debate on using nutrients transported by sewage water. At the moment, it seems that the stated role of nutrient cycling from wastewater or sewage sludge is over-estimated. Recent dissertations carried out at the Universities Hannover and Darmstadt prove that the efficiency of nutrient cycling lower than expected. Only a change in boundary conditions caused by the predicted shortage of P or K minerals or by high energy prizes (fixation of N via Haber/Bosch process) will promote to process urban sewage water in such a way that it will be reused as a risk free and good practicable manure in future agricultural and urban gardening systems (de Graaf et al., 2007, Schramm 2008).

According to Niemczynowicz (1999) the future challenges within urban water management will be to organize cross-sectoral stakeholder cooperation in order to introduce innovative water technologies, management systems and institutional arrangements. These systems should be able to meet the multiple objectives of equity, environmental integrity and economic efficiency, and at the same time achieve a high level of water services.

The scientific literature on water and food production in urban areas is dominated by the discussion on re-use of waste water, especially in the developing world. As such, there is a strong focus on areas under severe water stress (Middle east, North Africa, South-West USA).

Possible further inter linkages between the urban and agricultural systems have hardly been regarded. In the long run, the integration of organic waste (biodegradable section of waste) in urban sewage treatment plants might lead to synergies and more efficiency in the processes (Kluge et al., 2009). Processed wastewater and improved types of sludge might be used in urban gardening. Irrigation with wastewater will decrease overall water shortage and stabilize the urban ecosystems needed for urban climate adaptation.

4.2 Gaps in scientific knowledge

Hydrologically speaking, urban areas are blind spots. Many traditional measurement protocols are not valid in cities. Rain has to be measured away from buildings, which is impossible in a city. We have good models of sewage systems, but lack data on their functioning, especially during critical rainstorms. Reliable data about evaporation and groundwater seepage are scarce due to lack of monitoring. Urban agglomerations are becoming a more and more important part of a watershed. Hydrological process knowledge has to be collected in urban watersheds. The role of urban areas in the water cycle is regarded as an interesting research theme (cf. Holt & Pullen 2007). The diagram below presents a representation of the complete urban water cycle (De Graaf, 2009)

The implementation of innovative solutions is hindered by institutional barriers and technical lock ins. On the other hand, environmental and hygienic laws and recommendations are the drivers of innovations in urban water technology. To successfully implement new concepts and new technologies, they must be embedded in the socio economic system, that is: user practices, perceptions, guidelines, legal frameworks and markets. Mouritz (1996) argued that the design of future water infrastructure should be developed by integrated planning and management of land, water and other resources. Also van Rooy et al. (1998) stated that water is a part of our environment and that water policies interact with urban planning policies. In addition, each development should aim to improve the functions of natural water system to maximize local environmental and economic benefits (Ellis, 1995).

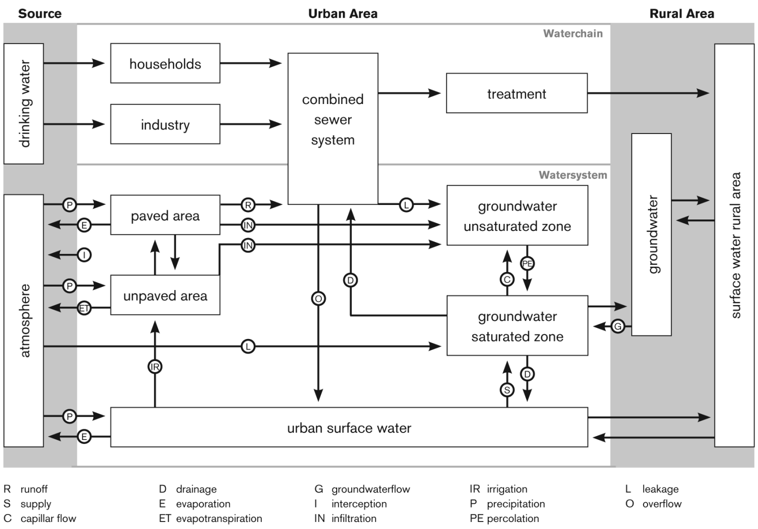

Figure 12. Urban water cycle

In the last 150 years there was a division of labour: This has led to isolated optimizations of each of the following systems: Water supply, sewage water disposal, energy supply, waste disposal and urban gardening. Institutional fragmentation has resulted in functional silos in which part of the system is optimized in isolation of other system components. This has led to a suboptimal overall system performance. Technical optimization of a component of a large technical system may prevent system innovation. Moreover, it may lead to a technical and institutional lock in. Different organizations are responsible for the interrelated components of urban water systems. Fragmented accountability frameworks of urban water organizations leave limited room for action that diverges from statutory responsibilities. Institutional objectives of urban water management organizations are focused on performing prescribed task within legal frameworks. There is no defined responsibility for the overall urban water system. Reward mechanisms are based on fulfilling procedures, within the boundaries of projected costs and projected timeframes (de Graaf 2009).

Recently, a transition oriented literature has emerged that focuses on how to move towards more sustainable environments. Researchers have become increasingly interested in the ongoing transformation of urban water systems. Changes in the urban water management approach can be classified as paradigm shifts, transitions, regime shifts or transformations (Van der Brugge & Rotmans 2006; Brown & Clarke 2007; SWITCH, 2006). The effects of climate change and developments such as urbanization, the European Water Framework Directive, and societal concerns about the sustainability of urban water system force the sector to adapt. Stakeholders are becoming more involved in urban water management. Urban water systems have to fulfil an increasing number of functions and are influenced by various conflicting values. Thus, the connection with urban planning and development, that is the process through which spatial functions are determined and values are negotiated, is increasingly important. Concepts such as Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID) and Integrated Urban Water Management (IUWM) reflect approaches in which the connection with urban planning and social amenity is highlighted. Most approaches stress the necessity of an integrated system approach that includes the total urban water cycle.

The main missing links in our knowledge concern:

- ***Understanding of the urban hydrological cycle***
- ***Overview of available and expected technologies***
- ***Transition management, stakeholder involvement***

Although one needs to differentiate between cities in the developed and developing world, and between existing urban areas and new developments, these three missing links are relevant throughout.

The components of the urban water system are interrelated and should researched in an **integrated** fashion. Wastewater, stormwater, drinking water supply, groundwater and surface water should be studied and managed by using an integrative approach. An important element in this approach is the use of an integrated, cross-sectoral, multidisciplinary institutional framework (e.g. Butler & Parkinson 1997; Niemczynowicz, 1999; Geldof and Stahre, 2006). Some authors consider the urban water system as a complex adaptive system (Geldof and Stahre, 2006) or sociotechnical system (Brown and Clarke, 2007) rather than a technical system. Not only the metabolism with the urban hinterland but also the urban water system as such can be seen as a social-ecological system.

4.3 Role of scientific research in support of policy

According to an international expert discussion "Sustainable Urban Water Infrastructure – Possibilities of Adaptation and Transformation" (2008 in Berlin, Germany, organized by the NetWORKS group) there will be major changes in urban water management during the next 20 years. Approaches towards a differentiated way of coping with water (e.g. supply with process water, separated treatment of black and grey water) are no longer only subject of pilot projects. Researchers from Australia, China, France, Germany, Israel, the Netherlands, Sweden, Switzerland, and the USA have confirmed that the central question of a purposeful design of the transition to a new infrastructure system is of high policy relevance. One of the challenges will be a management for this transition process allowing a “good governance” for the municipalities and their utilities (Felmeden et al. 2009, Kluge et al. 2007).

Besides the obvious links to the practice of city planning and development, there is an interesting additional policy angle with respect to the “battle for the minds”. Many cities in the developed world, but especially in Europe, see themselves faced with the fact that they have become less attractive to higher income citizens and have become the default dwelling place for the more “resources challenged” part of the population. It is recognized that cities will have to re-invent themselves and that they need to compete for the better brains that will produce the added value in the service and knowledge industries. A sustainable, healthy, and attractive environment are an important and explicit part of strategies by almost all European cities.
This desire to become “attractive” is now translated into actions and investments that are based on feel good ideas from the underbelly (more trees, green roofs, waterfronts, …). This research would ensure that these expensive PR campaigns will actually lead to more sustainable cities.

Outside the developed world, megacities with extensive non-planned city parts (slums and favelas) are often the rule. The development, operation and maintenance of water provisions and sanitation services for such huge agglomerations and the related impact of urban development on its natural resources, need special management concepts and tools. Varis (2006) summarizes the situation and future prospects of seven rapidly expanding megacities in various parts of the developing world: Jakarta, Johannesburg, São Paulo, Mexico City, Riyadh, Istanbul and Singapore. He concludes that megacities are dramatic cases of urbanization and water-related challenges. A main constraint is that even though the provision of water for various sectors is quite important, water is not the only aspect of infrastructure development needed in megacities. Transportation, energy and housing should also be developed (cf. above “inter linkages”). Research on transitions towards more sustainable cities would directly support Germany’s development aid efforts.

4.4 Role of German research

Germany has a very strong water sector when it comes to drinking water and waste water treatment (*Siedlungswasserwirtschaft*). To a large extent this experience has followed an “engineering” approach. In addition, Germany is traditionally strong with respect to urban and regional planning. In Germany, there have been noteworthy innovations in the past two decades in the field of alternative water supply and sewage disposal technology. To date, however, these innovations have only been implemented in a few, small-scale pilot projects. The specific experiences gathered through experimental housing and urban development projects do not, however, provide sufficient basis to draw general conclusions or do not indicate that the innovations are applicable in current terms for implementation on a larger scale and combined with existing facilities and networks.

Water and food in urban areas is clearly a field that is in its inception phase. Countries like Australia and Japan are somewhat ahead but mainly focus on their specific problems 9hazards and droughts). There is room for a strong program with a clear international outlook.

The real innovation that is needed is to lift urban water management above a narrowly defined sector approach. Linking water to all relevant aspects of urban development is a logical step. Sufficient institutes exist in Germany that can bring a more integrative approach to the table, building on previous experience with BMBF and EU research projects (GLOWA Program, UfZ, Uni-Osnabrueck, ISOE). With the mix of traditional technical strength, innovative integrators and a strong home market, a BMBF project in this field would (should) produce innovative strategies for the cities of the future.

5 Water and Food in Asia from a Global Perspective

Workshop "Future trends and research needs in water management"; 2nd to 4th February 2010 Osnabrück, Germany

Water and Food in South-East Asia from a Global Perspective

Water and food interrelationships are extremely high in South-East Asia. High population concentrations, large dependency on erratic rainfall, huge irrigation schemes, vulnerable to sea-level rise, and complex water competition issues make the area extremely important from a global as well as regional perspective. The region will be studied in a multi-disciplinary way, with a strong focus on risk and vulnerability issues. The study will be developed simultaneously with the global water-food framework to ensure linkages between and within the region and the global scale.

Major Conclusions

Gaps in scientific knowledge

- Intensive large scale irrigation is a key characteristic of Asian agriculture. There is a scientific gap in methods to assess the dependence of these systems on melt water, groundwater or local runoff.
- There is a gap in knowledge about the regionalization and timing of the effects of extreme weather events (droughts and floods) on crop failure.
- Climate-water-food hotspots in Asia are the Indus Basin Irrigation System and the Northern China plains, where water is scarce, demand is high, population is rising rapidly and hydro-political situation is tense. Adaptation research should focus on selected hotspots.
- The human dimension in water-food-climate research is weakly developed.

Science-policy interplay

- There is a continuously debate whether large scale irrigation is also benefitting the poorest of the poor. By integrating the physical and human sciences integrated analysis can be performed. Regions in Asia can serve as a case for this.
- Developments in Asia are often seen as a blue-print for Africa. The regional component of the global framework could serve to support decision making.

Relevance of international policy problem

- Himalayas are seen at the water tower for over two billion of people. Climate change will change melting of snow and glaciers. There is however no consensus to what extent this will influence food production in the region.
- Countries in Asia are running out of natural resources, including land to produce food. These countries are now heavily investing in Africa, including purchasing or leasin land for agriculture. Impact for Africa and Asia will remain high on the international policy agenda.

German Scientific community

- Germany has a couple of global initiatives with Asian components focusing on human dimensions of global change and water-food. At the same time are some universities active in Asia on developing physically based approaches on the same topics. Combining these two approaches would have the potential to create a very strong long-lasting collaboration on Asian research in Germany.

5.1 Gaps in scientific knowledge and potential to achieve scientific breakthroughs

During the last half of the 20th century tremendous advances have been achieved in terms of agricultural production in Asia (Pinstrup Andersen, 2004). At the same time, agriculture remains for livelihoods in Asia a key component and hence, of poverty and food insecurity in the region. It is projected that the proportion of food insecure people in Southeast Asia will decrease from 12% in the period 1997-99 to essentially zero in 2030 (Craswell, 2005). Other key issues for agriculture in the region will be the challenge of meeting the increasing demand for animal protein as incomes rise in Asia, and the accelerated pace of globalization and its implications for trade.

The physiography of most countries in Southeast Asia put additional challenges in terms of food and water in context to global change. Most countries comprise large hilly or mountainous areas and floodplains where water accumulates during the monsoon season. The floodplains are the high-potential areas, and especially important are the irrigated alluvial deltas that are intensively cultivated to rice (Craswell, 2000). Nevertheless, it is mainly in the extensive marginal hilly areas that one finds farms with low productivity and low incomes, with serious problems of food insecurity at the household level. It is in the high-potential area that the intensified production of staple grains has met demand and kept grain prices low for the urban poor. Continued high productivity from such areas is essential not only to provide food for urban populations, but also to reduce, at the national level, the pressure to intensify agriculture on marginal lands.

These high-potential floodplains are however prone to natural disasters (Lebel et al., 2009). Over the past thirty years the number and impacts of flood disasters has continued to increase across Asia (ABI 2005; Dutta & Herath 2004). This has occurred despite vastly improved abilities to monitor, warn and describe floods. In the region this in part reflects growth in absolute numbers of people living in flood-prone areas and higher values of infrastructure at risk (Nicholls et al. 2007); thus, around urbanizing regions new flood-sensitive settlements and land-uses are expanding into low-lying wetlands and rice paddy landscapes.

Important in the food-water-global change discussion in South-East Asia is the uncertainty in the so-called Water Tower function of the Himalayas. The admitted error in the 4th Assessment Report of the IPCC claimed:
"Glaciers in the Himalaya are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate.

However a recent article in Science (Immerzeel et al., 2010) provides a much more balanced, based on scientific approaches, conclusion. The authors' results show that Asia's water towers are threatened by climate change, but that the effects of climate change on water availability and food security in Asia differ substantially among basins and cannot be generalized. The effects in the Indus and Brahmaputra basins are likely to be severe owing to the large population and the high dependence on irrigated agriculture and meltwater. In the Yellow River, climate change may even yield a positive effect as the dependence on meltwater is low and a projected increased upstream precipitation, when retained in reservoirs, would enhance water availability for irrigated agriculture and food security (Figure 13).

Figure 13. Dependence on meltwater and rainwater for food production (Source: Immerzeel et al., 2010)

Asia is also prone to water shortage, despite the relatively high precipitation amounts some areas experience (Eriyagama, et al., 2009). Per capita availability of mean annual river discharge allows areas of both 'climate-driven' and 'population-driven' water scarcity to be identified (Falkenmark et al. 2007). A typical example of these two different water scarcities is the fact that due to India's higher population density, its water scarcity may be interpreted as 'population-driven' as opposed to 'climate-driven' water scarcity in countries like. Thailand, Pakistan and (Southeastern) China.

Based on the above several scientific gaps can be distinguished that vary in location and theme:

On a regional scale it is important to further quantify in space and time how the intensively irrigated agricultural systems such as the Indus Basin Irrigation System (IBIS), the Gangetic plains and the Northern China plains depend on either snow or glacial melt water from the mountains, groundwater or local runoff. At the regional scale it is also important to further develop methods to quantify the effects of extreme events such as drought and flooding on crop failure.

Key focus areas could be identified as hotspots where research on adaptation to climate change of irrigated agriculture could focus on. The IBIS and the Northern China plains are obvious choices. The Indus basin is hydro politically very sensitive given the tension between Pakistan and India, the Indus water treaty of 1960, over 140,000 km^2 of irrigated area, high population pressure and the high dependence on melt water and thus high susceptibility to climate change. On the Northern China plains the majority of grains are produced to feed over a billion Chinese. The plains are dry and unsustainable use of groundwater resources for irrigation results sharp drops in groundwater levels.

Adaptation measures should focus on modernizing irrigation systems and improving water productivity (e.g. more crop per drop), optimizing water allocation as most irrigations systems are fed by reservoir systems, development of less water consuming crops or crops that can survive short-term flooding and economic incentives to save water.

5.2 Science-policy interplay

It is clear that water-food in the context of global change has been changing rapidly over the last decades and will continue in the future in Asia. Especially the linkage with global issues is in this highly populated continent has a very high international science-policy interplay. Approximately 70% of the world's irrigated land is in Asia, where it accounts for almost 35% of cultivated land (Molden et al., 2007). The concept of virtual water is especially relevant for this region, and should be worked out further focusing on inter-annual as well as year-to-year variation.

In the densely populated areas, such as the rice growing areas of Asia, irrigated agriculture declines due to urban expansion. Also, it is a continuously debate whether irrigation helps to poverty alleviate poverty or whether irrigation contributes mainly to the somewhat better offs (Hussain and Hanjra, 2003.)

Finally, at the science-policy interplay the debate on large-scale infrastructure, such as reservoirs, irrigation, and basin-transfer is very relevant for Asia (WCD, 2000). However, since developments in Asia are often seen as a blue-print for development in Africa, there is a clear need for a retrospective analysis with a clear window to the future.

5.3 Relevance of international policy problem

For Asia there are two major issues that are high on the international agenda in the context of water-food and global change. The first one is the role of climate change and water for food issues regarding melting snow and glaciers in the Himalayas. Especially the discussion on mitigation versus adaptation is an emerging topic of the area.

Second international policy problem is the high population growth of Asia and the big demand on resources, including food, on particular Africa. It is well known that various countries in Asia, especially China and India, have an aggressive policy on obtained land in Africa to secure their food demand in the future. It is clear that a global approach is needed to study the impact of these actions on Asia as well as Africa.

5.4 Suitability of the program to be implemented in the German scientific community

The German research community has a broad interest in Asia. Some of the more global initiatives located in Germany (specifically Bonn) have often specific projects in Asia. A big step forward was the so called “Central Asia Water Initiative” (Berlin Process). In 2008 Germany's Federal Foreign Minister announced the launch of the Central Asia Water Initiative at the Berlin water conference “Water Unites”. The initiative was an offer from the German Government to the Central Asian countries to provide support in water management and make water the subject of greater cross-border cooperation.

From a more academic perspective some universities have developed strong research in Asia (e.g. ZEF and Jena). Large research projects such as Brahmatwinn are often focused towards the more physical components of the water-food-climate interactions. Combining these more physically based approaches with the earlier mentioned human dimensions would have the potential to create a very strong long-lasting collaboration on Asian research in Germany.

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'Advancing human security through knowledge-based approaches to reducing vulnerability and environmental risks'

UNITED NATIONS UNIVERSITY
UNU-EHS
Institute for Environment and Human Security

REPORT

Water related risks, vulnerability, and adaptive capacities under conditions of uncertainty

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Executive Summary

Vulnerability can be defined as *“the dynamic feature of an element at risk (population, community, region, state, infrastructure, environment etc.) that determines the expected damage/harm resulting from a given hazardous event. Vulnerability changes continuously over time and is driven by political, institutional, physical, social, economic and environmental factors”* (Thywissen, 2006). Although multi-level and causal vulnerability frameworks exist, in the context of natural and particularly water-related hazards, vulnerability research up-to date has achieved little progress to model the vulnerability of complex systems and to develop best practices for their governance. “Vulnerability” is not explicitly mentioned but reflected in the concept of Integrated Water Resources Management (IWRM) by emphasizing the need to understand the political, technical, social, environmental, and economic drivers and their links when dealing with water related problems. Even though the international disaster risk policy community promotes and calls for strategic and systematic approaches to reducing vulnerabilities and risks to hazards, the impact perspective still dominates over the vulnerability perspective. The increasing water related disaster risks due to climate change requires among other things the further advancement of IWRM, particularly in terms of the role of modeling and governing the vulnerability of complex systems. Because a lot of challenges exist with regard to the assessment and management of vulnerability of complex systems, priorities for areas of future research are: (a) Risk governance and institutional vulnerability, (b) Risk and adaptation related to urban dynamics and (c) Vulnerability of coupled Critical Infrastructures.

Risk governance research puts emphasis on understanding cross-scale, cross-sectoral and cross-border governance and institutional structures that regulate social-ecological systems and influence the configuration of water related disaster risks. With such analysis a “good risk governance” conceptual framework and monitoring system can be developed that includes quality criteria and respective indicators to facilitate and monitor disaster risk reduction in the context of IWRM.

Since risk and adaptive governance is a cross-cutting research domain it also applies to urban adaptation and dynamics, and coupled critical infrastructure vulnerability research. Both topics play a major role in vulnerability science; because vulnerability related trends in urbanization (shrinking in developed and rapidly growing in developing countries) and the increasing dependency of the population on critical infrastructure services (e.g. water and electricity supply) pose extraordinary challenges with regard to govern adaptation and disaster risk reduction. In order to develop resilience-based frameworks for the governance of cities and critical

infrastructure it is necessary to explore solutions and best practices how to deal with the uncertainties of climate change and the scientific shortcomings associated with downscaling the consequences of climate change. Hence, it is necessary to investigate on how to link research lines of urban and Critical Infrastructures studies with natural science approaches of climate change downscaling. In doing so, it is necessary to understand the institutional challenges in applying science-based climate change and vulnerability information for the development of adaptation options for urban agglomerations and Critical Infrastructures.

In this context, more urban related vulnerability research is needed that identifies the various trends of urban vulnerability dynamics and in particular the underlying processes and structures that shape the emergence of vulnerability and its patterns of rapidly evolving mega-cities and fast shrinking urban areas.

Regarding critical infrastructure related vulnerability research a key challenge is the development of a conceptual framework and respective empirical research lines that capture the vulnerability of coupled systems and interdependencies between Critical Infrastructures (CIS), society and environment. Such a framework and empirical research should also consider the influences of increasing deregulation and privatization of CIS services on the overall vulnerability and adaptive capacity of CIS and society. Additionally, the development of protection standards for resilient CIS and coupled systems of CIS, society and environment is needed that also provide guidance for governing the processes of critical infrastructure innovations (e.g. general digitalization of CIS, or “smart grids” in electric power supply).

1 Introduction

The report has been written within the overall frame of vulnerability and disaster risk research (see Birkmann, 2006, Bohle, 2001; Cardona, 2004; Cutter, 2003;; Wisner et al., 2004) and in the light of increasing climate variability creating the likelihood of increased water related disaster risk as well as long-term changes of coupled social-ecological systems (Linton, . Also for the international water research community the need has been recognized to focus more on understanding the social, economic and environmental and institutional drivers of water related risks and vulnerabilities in order to develop solutions to proactively deal with the growing challenges of climate change impacts.

After a first screening of relevant future research topics in this field of water related hazard and disaster risk research an in-depth analysis by distinguished scientists has been conducted during the workshop “Future trends and research needs in water management” (2nd to 4th

February 2010 and hosted by UFS, University of Osnabrück), and highlighted the following application areas as priority topics for future water related vulnerability and risk research:

- Risk Governance and Institutional Vulnerability (by UNU-EHS);
- Risk and adaptation related to urban dynamics (by UFZ);
- Vulnerability of coupled systems particularly linked to critical and supply infrastructures systems (by UNU-EHS).

The major goal of the report is to present an overview of each application area and to provide a first outline of key research questions and potential research projects in that particular research area. In this regard the analysis of each application is structured according to the following criteria:

(1) an introduction into the topic;

(2) a state of the art analysis of the respective topic;

(3) research gaps and future research needs;

(4) outline of a potential research project.

Further evaluation of each application area and proposed research agenda using the following sub-criteria:

- Gaps in scientific knowledge and potential to achieve scientific breakthroughs
- Relevance of international policy problem
- Suitability of the program to be implemented in the German Scientific community (critical stock of available expertise, potential to strengthen an emerging research community)
- Science-policy interplay- link to relevant stakeholders, efficiency and effectiveness of implementation, potential of a program to have real impact.
- Nature of implementation of the program (minimum duration of the program, kind of program, resource requirements)

Before dealing with the in-depth analysis of each application area, the following section will provide an overview of the three selected areas within the broader context of applied vulnerability and risk research in the field of water related hazards and particularly coping and adaptation strategies to climate change.

2 Assessing and managing the vulnerability of complex systems: Challenges for water related vulnerability research

Even if greenhouse gas concentrations stabilize in the coming years, impacts from climate change are unavoidable due to inertia related to bio-physical processes in the atmospheric, oceans and other global systems (dangerous climate change) (see Lenton et al., 2007). The resulting impacts include increasing water stress in many regions, more extreme weather events and consequently water related disasters that already today pose the highest threat to human development (Figure 2)

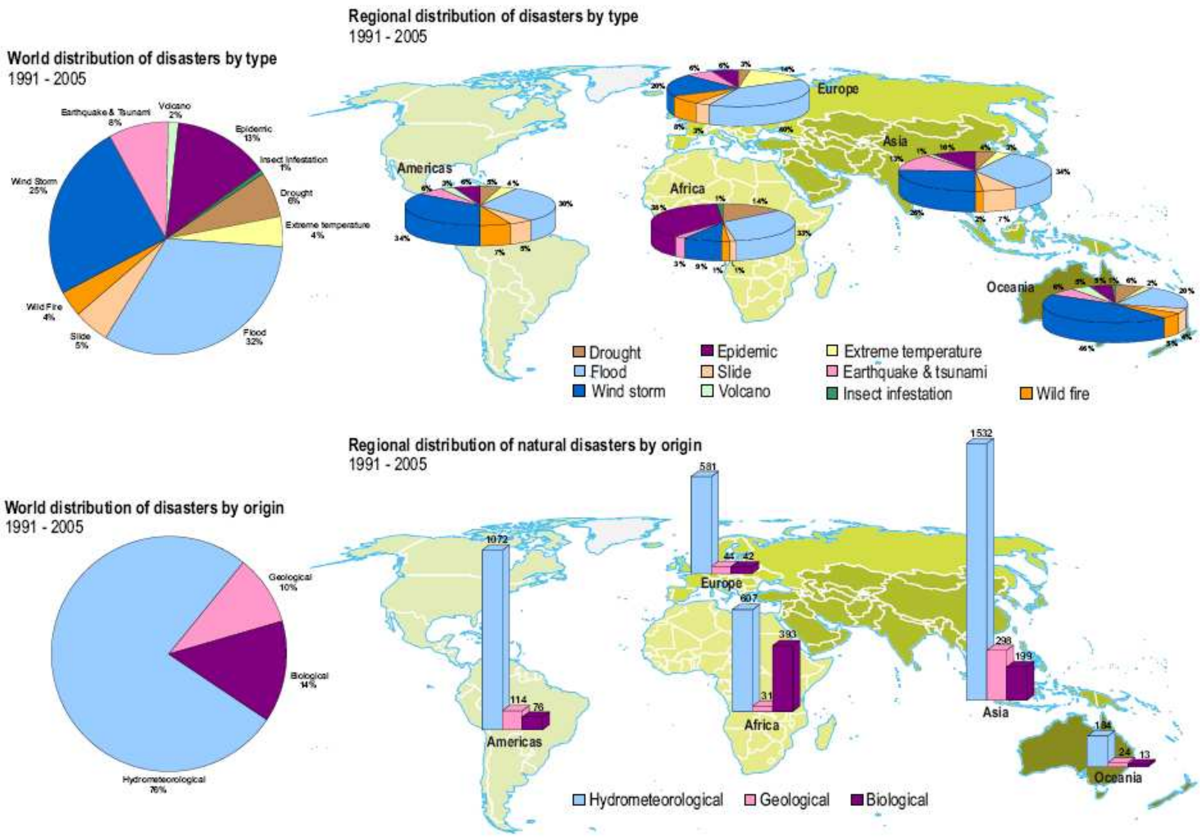

Figure 2: Regional distribution of disasters by type 1991-2005 (ISDR CRED 2007)

With the heading of Chapter 1 of the recently published World Water Development Report 2009 “Getting out of the box – linking water to decisions for sustainable development” (*UN-WATER* 2009, p xix) it is recognized that…:

> *“…Important decisions affecting water management are made outside the water sector and are driven by external, largely unpredictable drivers – demography, climate change, the global economy, changing societal values and norms, technological innovation, laws and customs, and financial markets.*

Many of these external drivers are dynamic and changing at a faster pace." (UN-WATER 2009, p xix)

In this regard the concept of Integrated Water Resources Management (IWRM) emphasizes the need to focus on political, technical, social, environmental, and economic drivers and solutions when dealing with water related problems. This is also particularly relevant when dealing with climate variability and change water related stressors and disaster risk. However, the idea to consider all aspects is still a major challenge, especially due to the various links between the drivers *(UN-WATER 2009, p 74, p.242).*

To be able to deal with the gap between water management challenges (under conditions of uncertainty and complexity in the context of climate change) and their manageability the *Regional and National Research Program Network on IWRM* (IWRM, 2009) poses the following questions:

- How to develop an understanding of cause-effects relationships of future impacts on the water system?
- How to develop inter-disciplinary tools and methods for IWRM (physical, ecological and socio-economic processes)?
- How could climate change affect water- and ecosystems?

(http://www.iwrm-net.eu/spip.php?rubrique8)

In order to understand and manage the cause-effect relationships of current and future impacts on the water system and develop adaptation strategies scientists and policy makers underline the need to examine the various vulnerabilities of systems exposed to water related hazards in a changing climate, rather than focusing solely on impacts (compare Kelly, M. & N. Adger, 2009; IPCC, 2001; UN, 2005). In this regard the final declaration of the World Conference on Disaster Reduction, ''Hyogo Framework for Action 2005–2015'', underlines the need to promote strategic and systematic approaches to reducing vulnerabilities and risks to hazards (United Nations 2005, preamble). The declaration points out that *"the starting point for reducing disaster risk and for promoting a culture of disaster resilience lies in the knowledge of the hazards and the physical, social, economic and environmental vulnerabilities to disasters that most societies face, and of the ways in which hazards and vulnerabilities are changing in the short and long term, followed by action taken on the basis of that knowledge." (UN, 2005)*

The different authors and policy documents call for improved risk-based approaches, however, the development of respective information systems and management approaches *(see WWDR 2009,* DAS 2008, UN 2005*)* often does not sufficiently capture the multi-faceted nature of vulnerability. Where the term vulnerability is used it is mostly related to exposure only or to the definition of unfavorable conditions, in which exposed populations in developing countries are living, such as poverty, income insecurity and low education. Thus most approaches link vulnerability to general factors of underdevelopment. The limited understanding of what vulnerability is all about in a wider context is mainly due to the fact that the impact perspective dominates over the vulnerability perspective. According to Vogel and O'Brien (2004) the impact perspective has traditionally been used to emphasize on the potential consequences of a particular event, while in contrast the vulnerability perspective draws attention to those factors – of human or environmental origin – that, together or separately, account for the vulnerability of the receptor, for example a community or ecosystem, leading to disasters (Vogel and O'Brien, 2004: 2). Thereby vulnerability can be defined as…

> *…"the dynamic feature of an element at risk (population, community, region, state, infrastructure, environment etc.) that determines the expected damage/harm resulting from a given hazardous event. Vulnerability changes continuously over time and is driven by political, institutional, physical, social, economic and environmental factors".* (Thywissen, 2006)

The definition underlines indirectly the need to focus also on "the vulnerability of complex systems". In this context cross-scale interactions and processes between different thematic dimensions (social, economic, environmental) play a major role. These interactions have also been taken into consideration by vulnerability frameworks that particularly stress the social-ecological perspective, such as the Turner et al. 2003 framework. Practical example of such coupling processes can be seen in coastal communities affected by water related hazards, as well as in the various interdependencies of societies in developed countries and their dependency on critical infrastructure services. (see Birkmann and Krings, 2008; Kaplan et al., 2009)

Although multi-level and causal vulnerability frameworks exist, vulnerability research up-to date has failed so far to model *the vulnerability of complex systems* and its dynamics. Also the ICSU Science Plan for Integrated Research on Disaster Risk (ICSU, 2008) stresses the fact that the dynamics of vulnerabilities are not well understood and calls for research on the dynamic modeling of vulnerability. At the same time, future research is required to provide guidance on how to manage *the vulnerability of complex systems* within multi-stakeholder environments, particularly taking into account different stakeholders, such as state-, private sector-, and civil society organizations. To improve the quality of decision making and to provide integrative management strategies research on water related risk and adaptive governance is needed that also considers multi-level and cross-boundary decision making in the context of natural hazards (ICSU 2008, IHDP, 2009).

These two perspectives on future research challenges, namely assessing and managing the vulnerability of complex systems and its dynamics, served as a basis to specify future research needs and to deduce three application areas for an in-depth analysis:

The application area "**Risk governance and institutional vulnerability**" is linked to the issue of root causes of vulnerability and addresses the challenges of managing *the vulnerability of complex systems*. Thus, issues of governance are also addressed when developing future research topics related to urban and critical infrastructure vulnerability. Risk governance "*looks at the complex web of actors, rules, conventions, processes and mechanisms concerned with how relevant information on the causal structure of vulnerability in hierarchical and complex social-ecological relationships is collected, analysed and communicated and how management decisions are taken*" (Renn, 2008, IRGC, 2005; see Biermann, 2007). Thus, risk governance can be regarded as how adaptation is conducted, where adaptation is defined as "*an adjustment in the ecological, social or economic system in response to observed or expected changes in climate stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities* (IPPC, 2001)." This definition of adaptation has similarities with the understanding of adaptation in the frame of IWRM. IWRM also stresses the need to focus on various adaptation aspects and drivers, such as very much fits political, technical, social, environmental, and economic drivers of adaptation when dealing with water related problems *(UN-WATER, 2009)*.

The other two application areas **"Risk and adaptation related to urban dynamics"** and **"Vulnerability of coupled critical and supply infrastructures systems"** are chosen, because they represent two very important topics of the vulnerability of complex systems that the world faces: How do trends in urbanization and de-urbanization and the increasing dependency of the world society on Critical Infrastructures interact with unknown and known changing environmental conditions such as climatic change that lead to increased water related disasters and long-term stress?

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3 Application area: Risk governance and institutional vulnerability

Research on disasters due to hazards of natural origin and particularly water related hazards primarily focuses on understanding the patterns of risk outcomes, by e.g. modeling flood inundation zones or assessing the exposure and vulnerable conditions of people (Handmer 1999). Natural sciences, geography, sociology, Engineering and spatial planning are the disciplines predominantly represented in recent vulnerability research. Although, the identification and assessment of vulnerabilities and risks of exposed elements is still an important research domain, another perspective on risk and vulnerability is currently raising attention of international scholars, i.e. the focus on regulatory aspects of risk and vulnerability. In this regard special attention is given to formal and informal institutions, rules and actors that regulate risk and vulnerability. The institutional dimension of disaster risk and vulnerability has been discussed for some years; however, only little research has been done in the field of vulnerability and risk governance and regulation. This is also a result of the fact that political and also legal scientists are underrepresented in natural disaster vulnerability research. Risk governance as a recently evolving research field has the potential for putting an advanced perspective on the institutional dimension of natural disaster risk, vulnerability, adaptation and resilience. Currently, this research discipline is prominently represented by the German sociologist Ortwin Renn (2008), whose scientific work on conceptualizing risk governance has significantly shaped the International Risk Governance Council's (IRGC) research and policy agenda (see IRGC, 2005). Although Renn and the International Risk Governance Council focus primarily on risk related to technical hazards and economic losses the methodologies and phases of the assessment can also be useful for enhancing the identification and assessment of institutional vulnerabilities within the context of disaster risk reduction linked to natural hazards and water related hazards in particular. Risk governance as the target and challenge to cope with increasing certain and uncertain water related disaster risk in the context of climate change gains much importance in the international policy dialogue since it addresses multi-level and cross-sectoral regulatory challenges by governmental and non-governmental stakeholders to reduce risks in complex societal and political environments (see Pahl-Wostl, 2009; MIDIR, 2008; IHDP, 2009; ICSU, 2008).

3.1 Scopus analysis

To assess the current state of development in this field of research, a bibliometric analysis of publications using SCOPUS database has been conducted for the time period of the past 10 years. Different combinations of key words in the context of the overall topic were inputted into the search engine. The combination of the different key words (Figure 2) was chosen to explore the trend on the role of governance and institutions in vulnerability science. The results show for each combination of terms the number of publication in peer reviewed journals in the search space of ‘articles’, ‘proceedings papers’, ‘reviews’, and ‘editorial material’ that included the ‘search terms” in abstract, titles or key-words.

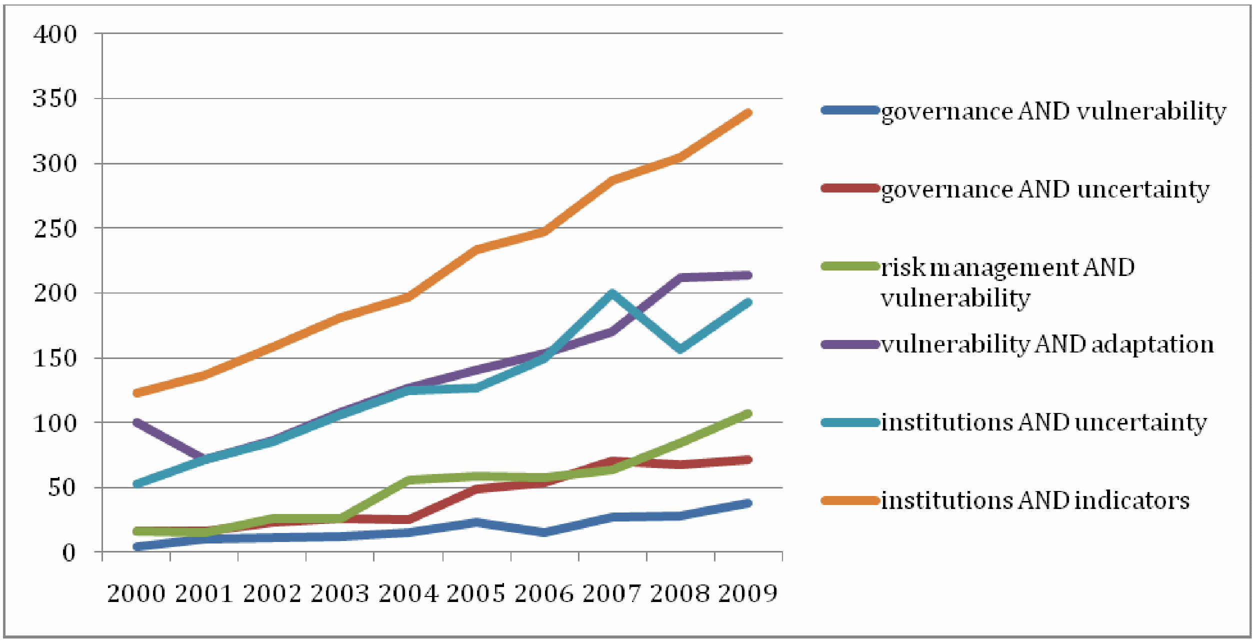

Figure 2: Number of publications regarding governance related to institutions, vulnerability and uncertainty in peer-reviewed journals.

The results show for all combinations of key words that number of publications using these key words has increased by 100%. Particularly, the topics of “governance and vulnerability”, “governance and uncertainty” have not been addressed as much in publications as the others, but since 2000 there is significant increase showing growing interest in this young research field. Interestingly, the topic of “institutions and indicators” has been addressed more often in scientific publications then the others issues examined within the analysis. The implications of these trends will be outlines in the following chapters.

3.2 Institutional vulnerability and limitations of applied adaptive capacity research

This chapter aims at providing an overview about the recent trends in the research domains of institutional vulnerability and adaptive capacity. Thereby, short-comings of the concept and assessment of adaptive capacity will be outlined to lead over to argue about the importance to focus on risk governance and regulation.

Institutional vulnerability can be defined as the institutional fabric of state organization; private sector and civil society that influences the likelihood of damage or harm as well as the unusual difficulties in recovery of elements at risk (e.g. citizens, economy, infrastructures, environmental services) that are impacted by a hazard event (water related hazard). Institutional vulnerability changes continuously over time and is driven by political, legal, social, cultural, economic and environmental factors at multiple scales. Thus, institutional vulnerability research does focus on the role of institutions in avoiding or creating risks and vulnerabilities of exposed elements. Institutions are defined as rules or norms which define the roles, rights and responsibility of actors (Young, 2002). Households, communities, firms or states, can represent such organizational entities that encompass various institutions and rule systems, which can be formal rules (e.g. legislation) or informal rule systems (social norms or customs) (Lebel, Nikitina, Kotov, & Manuta, 2006). These institutions tempt to reduce uncertainty of interaction between different stakeholders (North, 2005).

Whereas the sciences of *new institutional economics* is dealing with the analysis of the impact of institutions on the economy (North, 2005), institutional vulnerability research linked to disasters due to hazards of natural origin such as water related hazards in particular, focuses on the role of institutions that shape vulnerability and risk to natural hazards and climate change – including adaptation processes. The institutional dimension of vulnerability is well reflected by international research scholars. E.g. Adger et al. (2007) recognizes that there are many examples where institutions such as social relations, economic structures, values, perceptions, customs, traditions, levels of cognition and those forming formal governance affect the capability of communities to adapt to risks related to climate change (Adger et al., 2007). Wisner et al. (2004) addresses in his Pressure and Release Model (PAR) risk creating configurations of institutional setups as root causes of vulnerability. They argue that addressing vulnerability requires solutions that include political change, radical reform of the international economic system, and the development of public policy and regulation to protect rather than exploit people and nature. Special institutional challenges in the current scientific debate on risk and vulnerability arise from anticipated climate change challenges. In this sense climate change and water related stress becomes a risk factor unless the system is able to adjust to the changing conditions and engage in adaptive actions (Lim, Spanger-Siegfried, 2005). Thus, the capacity to adapt is a critical element of adaptation processes. "*It is the vector of resources that represent the asset base from which adaptation actions can be made*" (Adger & Vincent, 2005). There is a growing recognition that vulnerability and the capacity to adapt to climate change are influenced by multiple processes of change at multiple levels and thus is highly differentiated, also within countries (O'Brien and Leichenko, 2000; Turner et al., 2003; Luers, 2005; Leichenko and

O'Brien, 2002; Dow et al., 2006; Smit and Wandel, 2006; Ziervogel et al., 2006). E.g. economic consequences of trade liberalisation are likely to have both positive and negative consequences for the overall adaptive capacity of cities and regions (Pelling, 2003; Adger et al., 2007). Furthermore, studies carried out since the IPCC Third Assessment Report (TAR) show that adaptive capacity is not only influenced by economic development, but also by social trends such as urbanization and factors such as human capital and governance structures (Klein and Smith, 2003; Brooks and Adger, 2005; Naess et al., 2005; Tompkins, 2005; Berkhout et al., 2006; Eriksen and Kelly, 2007).

A significant short-coming of adaptive capacity research is its missing link to adaptation outcomes. There is some evidence that for assessing adaptive capacity and vulnerability national-level indicators are used by climate change negotiators, practitioners, and decision makers in determining policies and allocating priorities for funding and interventions (Eriksen and Kelly, 2007). However, few studies have been globally comprehensive, and the literature lacks consensus on the usefulness of indicators of generic adaptive capacity and the robustness of the results (Downing et al. 2001, Moss et al., 2001; Yohe and Tol, 2002; Brooks et al., 2005; Haddad, 2005). A comparison of results across five vulnerability assessments shows that the 20 countries ranked 'most vulnerable' show little consistency across studies (Eriksen and Kelly, 2007). Haddad (2005) has shown empirically that the ranking of adaptive capacity of nations is significantly altered when national aspirations are made explicit. He demonstrates that different aspirations (e.g. seeking to maximize the welfare of citizens, to maintain control of citizens, or to reduce the vulnerability of the most vulnerable groups) lead to different weightings of the elements of adaptive capacity, and hence to different rankings of the actual capacity of countries to adapt. It is these uncertainties and thus a major limitation of the concept of adaptive capacities because it emphasizes on the resources available for adaptation where no evidence can be found whether these resources of adaptive capacity can predict positive adaptation outcomes (Adger & Vincent, 2005). Here, risk governance science has the potential to develop conceptual foundations and management tools that are capable to better provide guidance for desired adaptation outcomes.

3.3 Research needs and gaps: Risk governance for sustainable disaster risk reduction

Since by empirical evidence assessing adaptive capacity cannot predict adaptation outcomes (at least there is a high level of uncertainty, see previous chapter) new approaches are needed that serve as a valid knowledge bases for taking decisions about adaptation funding priorities and for guiding countries, authorities and other relevant stakeholders to successfully govern vulnerability and risk. Here research on risk governance is a key. The basic difference between adaptive capacity and risk governance research is that the latter focuses more in-depth on policy and decision- making processes that influence those conditions that can alter adaptive capacity and vulnerability (Smit and Wandel, 2006). Thus, instead of focusing solely on the analysis of general adaptive capacities the research on adaptive governance performance advances the research focus, since it enables the development of monitoring systems that evaluate desired risk governance processes and outcomes. The emerging literature on the institutional requirements for adaptation suggests that there is an important role for governments (formal institutions) and respective public policy in facilitating adaptation to climate change (Few et al., 2007). This includes reducing vulnerability of people and infrastructure, providing information on risks for private and public investments and decision-making, and protecting public goods such as habitats, species and culturally important resources (Haddad et al., 2003; Eakin Callaway, 2004; Haddad, 2005; Tompkins and Adger, 2005). However, what this literature often overlooks is the fact that governments face various constraints in implementing risk reduction and adaptation measures, due to the fact that for example water related risks and vulnerabilities do not emerge within administrative units and that large organizations such as governments are complex, with a diversity of stakeholders, capacities and resources. In addition, they operate in the context of uncertainty (e.g. climate change and global change) and ever changing conditions and capabilities of social-ecological systems that are hard to predict. Therefore, risk reduction and adaptation measures developed by governments are not an easy task; rather they are embedded into various uncertainties (MIDIR, 2008). The absence of adaptive management and governance rules, procedures and capacities that cannot deal with non linearity and emergence are one of the major and cross-cutting drivers for vulnerability to water related stress and climate change because it limits sectors and institutions to take advantage of the opportunities or benefits arising from these threats (Adger et al., 2007). Opportunities and benefits that arise from threats are in the first place that governments are set under pressure and consequently urged to accelerate the introduction and facilitation of change.

In their effort to measure governments' and formal institutional performance to manage natural disaster risks Lebel et al. (2006) structure "institutionalized capacities and practices" into four clusters, which in their absence and mal-function factor vulnerability and lack of adaptive capacity of formal institutions: Deliberation and empowerment (consensus building), coordination (legislation, policies), implementation (programs) and evaluation (learning). These aspects can be studied on the systemic, organizational and individual level (MIDIR 2008). Although concepts of governance performance research exists (e.g. sub-national and national level good governance analysis conducted by the World Bank; Kaufmann & Kraay 2007), Pahl-Wostl (2009) argues that the analysis of multi-level and complex adaptive governance systems is an underdeveloped area of research and that its analysis has been mostly lacking a multi-disciplinary focus (Young, 2008). Consequently complex adaptive governance related to natural hazards is lacking that accounts for the social-ecological challenges of uncertainty and surprise in the context of climate change. In order to overcome the shortcomings of generic and simplistic approaches but still being able to "support context sensitive analysis without being case specific" a diagnostic approach for the analysis of adaptive governance has been called for (Ostrom, 2007; Young, 2008). Thereby, variables of interest can be selected and organized in a nested, multitier framework that is designed to account for a systemic perspective and to "consider complexity and wealth of interactions, which characterize governance regimes" (Pahl-Wostl, 2009). In the field of disaster risk research with regard to water related creeping and sudden onset hazards the concept of risk governance as an adaptive governance complex can serve as a starting point for the development of further research questions in the domain of applied governance research. Risk governance is of particular importance in situations where there is no single authority to take a binding risk management decision, but where the nature of the risk requires the collaboration of and coordination between a range of different stakeholders.

Here, the development of a set of predefined quality criteria and standards for good risk governance bears the potential to evaluate adaptation and risk management processes and outcomes against benchmarks. But neither adaptation guidelines nor clear normative concepts exist that aim to reduce vulnerabilities and disaster risk. Thus, one of the major research tasks identified is to "translate the substance and core principles of governance to the context of risk and risk related decision making" (Gunningham et al., 1998) first and then develop criteria and indicators for good risk and adaptive governance. In this context also a framework analysis is needed as well as procedural recommendations on how to use such criteria within actual risk management approaches at different levels. With such concepts, methodologies and indicators at hand, the shortcomings of the static analysis of adaptive capacity can be addressed. Other than adaptive capacity research, risk and adaptive governance research also looks at both the process and outcomes of adaptation: It allows for the assessment and comparison of institutional adaptation performance by evaluating decision-making systems that favor or limit institutional change and adaptation investments by governments and the private sector.

3.3.1 Theoretical and conceptual research needs for "good risk governance"

The term "good risk governance" is a clearly a normative concept that implies a further operationalization of what is meant with good risk governance. Conceptual work on risk governance has been carried out internationally and in the German scientific research community. Well known representatives of this research domain are amongst others (see chapter 3.5.d) Ortwin Renn, who is member of the "International Risk Governance Council" (IRGC), and who published amongst others the outstanding monograph "Risk Governance, Coping with Uncertainty in a Complex World". Initial point of emergence is a new concept of risk, which OECD has named “systemic risks” (OECD, 2003). The term implies the embeddedness of any risk to human health and the environment in a larger context of social, financial and economic consequences: “Systemic risks are at the crossroads between natural events, economic and technological developments, and policy driven actions, all at the domestic and the international level” (Renn, 2008:5). Thus, handling systemic and non systemic risks are thought to include the following normative cornerstones of risk governance: Hazard identification, risk assessment, concern assessment, tolerability/acceptability judgments (risk evaluation), risk management, and risk communication as a cross-cutting governance task (Renn, 2008). Each of the main components of this risk governance concept includes various sub-components and procedural guidelines developed based on a variety of theories, mainly social science. Although the framework shows substantial scientific progress, the conceptual foundation of risk governance developed by Renn (2008) is applicable mainly to technological risks and has various pitfalls regarding its suitability for natural disaster risk governance. For example, the role of vulnerability assessment is limited to an exposure analysis, although managing *the vulnerability of complex systems* is a key for overall risk reduction. Also processes of exposure manifestation in disaster risk (of natural origin) research are a complex spatial and social-ecological issue that needs to be taken into account when studying risk governance across scales and sectors. In addition the disaster cycle is not recognized in existing risk governance concepts although research programs such as the IHDP-Integrated Risk Governance Project (IGR) acknowledge the disaster risk cycle in their Science Plan (IHDP-IRG, 2009). The disaster cycle is important for examining institutional vulnerability and risk governance structures, since the different phases outlined in the disaster cycle also imply the involvement of different institutions according to their responsibility.

Overall, the following theoretical, conceptual and empirical research needs in risk and adaptive governance linked to water related hazards can be summarized as key challenges for future research:
Evaluation of existing risk and adaptive governance frameworks regarding their suitability for disaster risk reduction in terms of water related hazards in the context of climate change;

- Development of a “good risk governance” conceptual foundation including core principles, (sub-) components and procedures for water related fast onset and creeping hazards that emphasis on the role of assessing and managing the vulnerability of complex systems in the overall governance process.
- Developing of quality criteria for “good risk governance” with regard to all facets of risk governance: from deliberation and empowerment, to coordination, implementation and evaluation.

- Exploring the challenges regarding governing uncertain hazard impacts and their spatial distribution. In this respect it is also important to examine the imitations of governing water related hazards and vulnerabilities within the existing boarders of administrative structures. Special emphasis should also be given to the need to advance and amend the guidelines for IWRM in this context.
- Understanding the cultural dimension of risk governance in the context of uncertainty

3.3.2 Criteria and indicators for "good risk governance"

Indicator development is crucial for the support of policy and institutional analysis, as well as for taking decision on priorities for development assistance and investments aiming at improving good risk governance. The development of criteria and indicators to improve decision making also in disaster risk research is not a totally new topic (see Birkmann, 2006). Economic indicators had already emerged in the early 1940s (Hartmuth, 1998; Reich and Stahmer, 1983). Today, economic indicators such as ''GDP'' or ''HDI" are broadly used (and politically accepted). In the 1960s and 1970s the development of social indicators was a hot topic in the social sciences (Cutter et al., 2003), which crossed over into the political and social arena during the protest movements in the 1960s in the United States and Western European countries (e.g. Empacher and Wehling, 1999). The development of environmental indicators followed in the 1970s, linked to the establishment of environmental policies. A big impetus for indicator development emerged from the discussions about sustainable development. In this context various approaches to defining and operationalising sustainable development with indicators were undertaken (UNCSD, 1996; Birkmann, 2004).

The development of criteria and indicators that assess governance processes is a quite difficult undertaking due to the complexity of multi-level risk and adaptive governance systems in which abstracting and simplifying governance complexity but developing robust criteria and indicators is the balancing act. There is substantial experience within a similar field of research and application since 1992 (Woods, 2000). The donor institutions such as the World Bank, the International Monetary Fund, the European Bank for Reconstruction and Development, and the Asian Development Bank and donor nations have an interest in assessing the level of governance in countries where they borrow money for economic and administrative development projects (UN-DESA, 2007; Kaufmann & Kraay, 2007). Thus, the development of good risk governance indicators can benefit from vast experiences with governance evaluation processes and their methodological challenges such as data collection, sampling, validation of proxy variables, and the applicability of results.

Overall, criteria and indicators for good risk governance in terms of water related hazards are implying the following research needs.

- Evaluation of existing criteria and indicators for good governance and risk governance in terms of their performance and transferability to issues related to risk and adaptive governance in the context of water related natural hazards.
- Development of systemic as well as contextual indicators and criteria for "good risk governance". These indicators and criteria should be applicable at different levels of governance.
- Development of a monitoring system for "good risk and adaptive governance" related to water related hazards and climate change that can be used by different stakeholders.

3.4 Evaluation of the application area

a) Gaps in scientific knowledge and potential to achieve scientific breakthroughs

Up-to-date considerable research has been conducted related to the development o governance frameworks and indicators aiming at analyzing and monitoring democratization processes in developing countries as well as governance performance related to public participation and service delivery, economic development facilitation and poverty eradication (Kaufmann & Kraay, 2007). But for managing the vulnerability of complex systems, disaster risk and climate change adaptation a risk governance performance related analytical framework and globally comparable indicators and criteria for good risk governance do not exist (e.g. UN/ISDR, UNFCCC). Hence, governance assessment guidelines and indicators are needed that are generic for international comparison but valid enough for country specific assessments.

For the development of good risk governance theoretical and conceptual foundations and respective indicators (acknowledging the disaster cycle) future research needs to focus first on understanding cross-scale and cross-border interactions of the diverse set of regulatory and institutional mechanisms (with different regulatory culture of institutions and governments, sector policies at different scales, from local to global) that either create, intensify or manage the vulnerability of complex systems. This is especially true with regard to conflicts between social, economic and environmental developments and policies. Second, also the problem of developing benchmarks and quality criteria to determine the quality of governance performance in relation to the problem pressure and the overall capacity of a government and governance regime needs to be solved. The potential to achieve scientific breakthroughs is given, since there is tremendous experience (see Scopus analysis, e.g. "governance and indicators") and long history on governance research in neighboring governance research disciplines (e.g. development studies), from which good risk governance research can benefit.

b) Science-policy interplay

Since governance research deals with e.g. policy, decision-making and institutional structures the development of policy analysis tools needs to integrate the views and expectations by policy makers in order to generate acceptance of the results. Hence, the development of theory based good risk governance conceptual frameworks and indicators that shall be internationally standardized and utilized by relevant government and non-government organizations requires the involvement of policy makers, such as the disaster risk and climate change adaptation community, from the beginning in the research process.

c) Relevance of international policy problem

Climate change impacts and natural disaster risks are increasing world wide as at the same time trends of exposure and vulnerability intensification is a global phenomena, too. The international climate change and disaster risk policy community is just about to develop monitoring tools for adaptation and disaster risk reduction performance. Therefore, a research project aiming at developing analytical frameworks and monitoring tools for risk and adaptation governance is of high relevance to the current climate change policy community.

d) Suitability of the program to be implemented in the German scientific community

Germany bears a great potential to form a multi-disciplinary group of scientists representing the complex nature of the application area. First, just to mention a few, considerable conceptual competence related to (water) governance, indicator research that exists in Germany are for example the Institute of Social Science, University of Stuttgart, where Ortwin Renn leads the sub-directorate of technological and environmental sociology and the Institute of Environmental System Analysis, University of Osnabrück, headed by Prof. Pahl-Wostl. Second, social-ecological research competence is concentrated at various research institutes and programmes in Germany, for example the UNU-IHDP Programme based in Bonn and the Institute for social-ecological research based in Frankfurt. Third, there is a great amount of research competence associated with natural disaster risk research, such as the Center for Disaster Management and Risk Reduction Technology (CEDIM), the Department of Geography, University of Bonn (leading an interdisciplinary risk initiative), UNU-EHS and the Potsdam Institute for Climate Impact Research (PIK). Research Programmes with an inter-disciplinary focus on vulnerability and risk research include the Helmholtz-EOS-Programme, RIMAX and the IWAS initiative. Research communities in the field of political and law science in Germany have a long history and various institutes are specialized in environmental policy and law, such as the University of Hamburg. But their collaboration with interdisciplinary research programmes and institutes in disaster risk research needs to be strengthened.

Overall, the relevant research landscape that exists in Germany as outlined above is very well connected with the international academia and policy system. This is especially true for the University of Stuttgart, Osnabrück, UNU-IHDP, UNU-EHS, CEDIM, Helmholz-EOS and PIK.

3.5 Research project outline

A research project shall focus on the development of an internationally well accepted and theory based conceptual framework for risk and adaptive governance. The development of the conceptual framework for risk and adaptive governance with regard to water related hazards in the context of climate change should be supported by the development of respective criteria and indicators for good risk and adaptive governance in the water sector. In order to be scientifically sound, a case study based research design should be developed that allows for a systematic global comparison of institutional frameworks and structures for risk governance of water related threats by comparing case study specificities that need to be defined during the course of case study selection. Some criteria that are considered as important are: distinct regulatory culture and governance and national government architectures in place (e.g. centralized vs. decentralized systems or government vs. governance regulative cultures), degree of national government and governance capacities to manage water related risks, degree of problem pressures and experience with water related stress, climate and environmental change. With such a diversity of framework conditions that are attributed to states and governments it will be possible to develop a good risk governance framework and respective indicators that allow the integration of place specific contextual factors of governance as well as generic factors.

Since water related risk governance analysis is considered as an important dimension of social-ecological research a trans- and multi-disciplinary research group composed of researchers representing law and policy, economic, political, social, and natural sciences shall be set up. Furthermore, it is important to take into account the perspective of applied research and to develop knowledge that can improve decision-making processes. Consequently also experts from international and national organizations (e.g. OECD, UN-System, and Development Banks) as well as governments should be involved while designing case study research and respective criteria for good risk and adaptive governance.

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4 Application area: Risk and adaptation related to urban dynamics

This application documents the state-of-the art with regard to water-related natural hazards such as floods, droughts, flash floods, sea-level rise etc. and how they relate to urban dynamics. The document pays particular attention to the interrelation between the natural and the social urban system and highlights the relevance of urbanisation processes and how they might contribute to the emergence of vulnerable conditions.

The relevance of taking a ‘urban perspective’ is given by the sheer number of people living in urban areas and the ongoing unplanned and unregulated rapid urbanization process. Meanwhile more than half of the earth’s population is classified as living in urban areas (Simon, 2007); a trend which is likely to continue unbrokenly in the next decades. It is expected that in 2025 even two-third of the global population will live in urban areas (Roy, 2009). Consequently, many small and intermediate cities are experiencing rapid growth rates and the number of so called mega cities also increases. It is projected that more than 600 million people will live in 60 mega cities (i.e. cities with more then 5 billion inhabitants) in 2015 (Kraas, 2007).

However, the trend of rapid urbanisation is not taking place evenly: More than two-third of these cities are located in the so called ‘developing’ countries in the global south. Particularly these cities are characterized by explosive growth of population, polarizing processes leading social fragmentation, capital accumulation and of low economic development at the same time and poor environmental conditions (Roy, 2009). These urbanisation processes are resulting in an increasing exposure of people, buildings and infrastructures to water-related natural hazards. The exposure will most likely be amplified by the negative consequences of climate change as particularly rapidly developing urban areas are vulnerable to the consequence of climate change (IPCC, 2007). However, there are also inner-urban dynamics, such as an increasing population density within specific urban areas and neighbourhoods, social exclusion, inequality and marginalisation resulting in a heightened vulnerability of people and urban systems (e.g. Kraas, 2007).

Yet, it would be to short-sighted to exclusively emphasize the mentioned developments. First, particularly in Europe and Northern America cities are not only fast growing; many cities show processes of decline and shrinkage (e.g. Kabisch et al., 2004; Oswalt and Rieniets, 2006). Second, the process of urbanisation also creates benefits and opportunities as, for instance, economic growth may take place and many urban centres are the places of innovation (Simon, 2007). Cities may have considerable resources as well as coping and adaptive capacities to deal with both rapid changes (e.g. flash floods and floods) and creeping changes (droughts or sea-level rise). It is therefore surely no exaggeration to state that cities are in relation to climate change “one of the most important battlefields, with their higher concentration of population, economic activities and material and energy consumption, as well as offering the opportunity to investigate novel and replicable solutions” (Roy, 2009, 276).

The following paragraphs give an overview about the current state-of-the art knowledge in the area of “Risk and adaptation related to urban dynamics”. Therefore it distinguishes in two overarching topics of “urban dynamics, risks and vulnerabilities” as well as “urban adaptation challenges”. The report neither goes into definitional debates (although they will be made explicit, if the subject requires it), nor does it deal with each topic in-depth; it rather concentrates on interconnections and general trends on a global scale. If appropriate it will outline regional differences and/or commonalities, which appear as relevant for an overview article on state-of-the-art knowledge in the mentioned area. As outlined in the introduction two topics will be paid particular attention; that is the rapid growth of urban areas as well as the decline and shrinkage of urban areas. It will also be specified which challenges arise when adapting urban areas to global environmental change. The single paragraphs are structured as followed. At the beginning a short and general overview about the topic is given as well as the state-of-the art knowledge and empirical evidence with regard to the topics is presented. In a second step research needs that should be addressed in future research are specified. Finally, the possible configuration of a research project is outlined.

4.1 Scopus analysis

To assess the current state of development in this field of research a bibliometric analysis of publications using SCOPUS data base. Different combinations of key words were used to define ‘search terms’. The research results include the number of publication in peer reviewed journals in the search space of ‘articles’, ‘proceedings papers’, ‘reviews’, and ‘editorial material’ that included the ‘search terms” in abstract, titles or key-words.

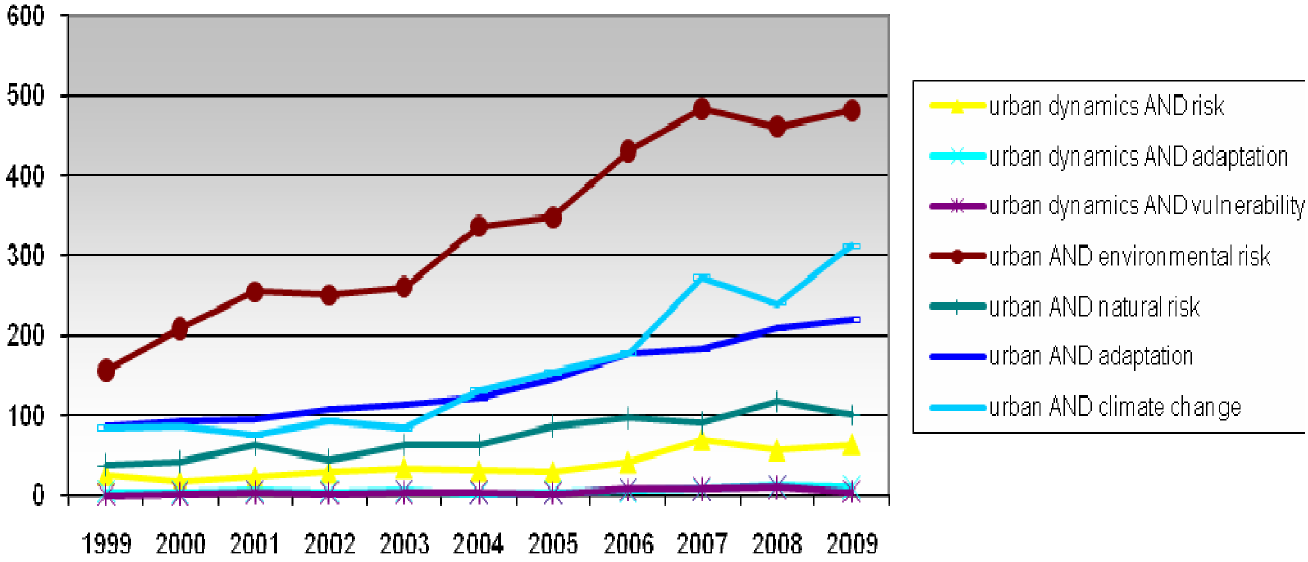

Figure 3: Bibliometric Analysis in the field of Urban Dynamics, Risk and Adaptation

Figure 3 highlights that there is a general increase of publication on the terms searched. Particularly, the topics of 'urban AND climate change' as well as "urban AND environmental risk' and 'urban AND adaptation' have gained recognition in recent years. All three topics will be dealt with more in depth below.

4.2 Urban dynamics, risks and vulnerabilities

Which processes contribute to an increase of urban vulnerabilities and risks? There seems to be a large consensus that three distinct processes, which are obviously interlinked and reinforcing each other, contribute to an increase of risks and vulnerabilities in urban areas (Simon, 2007). In the following the process will be outlined.

4.2.1 The inter-linkages of urban dynamics and global change

First, urbanisation processes as such are contribute to environmental changes due to their strong development dynamics, achieving unprecedented high spatial and demographic expansion, concentrations of population, infrastructure, economic power, capital, and decision-making, a high level of energy consumption, burning of fossil fuels as well as an excessive and partially self-energizing acceleration of all the mentioned development processes (Kraas, 2007; Simon, 2007; Roy, 2009). Particularly mega agglomeration affect "global change – understood as global environmental as well as socio-economic and political change […] – just as profoundly as global change effects" mega urban agglomerations (Kraas, 2007, 80).

Second, environmental changes affect the urban system, as urban areas are defined by high concentration of population, economic stocks, and infrastructure. Urban areas are in this sense vulnerable to slow moving and rapid approaching environmental changes such as sea-level rise, tropical cyclones, flooding and land-slides, water crisis, and heat and cold waves (Roy, 2009; Simon, 2007). These environmental processes may become even more severe under conditions of global environmental change resulting in an increasing frequency and severity of extreme events, ranging from spring tide to hurricanes and heat-waves; as well as a range of slow onset events or trends, like rising sea levels and increasing atmospheric temperature, with semi-permanent or permanent impacts on the urban system (Simon, 2007, 77). Although real progress has been made in improving state-of-the-art of climate change assessment (Cameron, 2006; Jones, 2000; Le Treut et al., 2007; Walker et al., 2003; Wilby and Harris, 2006), there is still a need for further specifying the impacts of climate change for specific urban areas and to integrate these top-down perspectives also with bottom-up perspectives. There is hence a need to integrate so-called “endpoint” and “contextual” approaches to vulnerabilities (cf. also O'Brien et al., 2007). While the first approach follows a top-down perspective and considers which impacts climate change has on urban areas, the latter approach follows a bottom-up perspective and considers how society is vulnerable to and adapts to climate change. The contextual vulnerability approach considers vulnerability as a starting point for the development of adaptation strategies. In this understanding, the emphasis is not so much on the natural system or the exposure of the urban area, but more importantly, on urban processes, structures and developments contributing to the overall urban vulnerability on the one hand and the more specific vulnerability of particular groups on the other hand.

Third, processes, interactions and dynamics within the urban system are contributing to an increase of risks and vulnerabilities of urban areas: While some urban areas are experiencing rapid urbanization processes; others are experiencing shrinkage and decline.

Urban areas that are defined by rapid urbanization processes are most often characterized by a general increase of their vulnerability as there are simply more people exposed to hazards (Laukkonen et al., 2009, 288). However, by urbanisation processes the urban population becomes also more fragmented and split in different socio-economic groups resulting in the further concentration of vulnerable households on land sites exposed to water-related hazards (Hardoy and Pandiella, 2009). Societal factors influencing the vulnerability of households are, among others, the income of urban dweller (Hamza and Zetter, 1998, 291; Pelling, 2002), gender, age, as well as migration status (Bartlett, 2008; Kantor and Nair, 2005; Wehrhahn et al., 2008). Other possible factors contributing to the vulnerability of specific groups are: irregular and casual employment, low and irregular income, size of household, health, education, living standards, social and financial resources (Kantor and Nair, 2005).

Furthermore, informal settlements are vulnerable to water-related hazards as buildings are usually built incrementally over a numbers of years, with materials of diverse origin and quality, and not always following accepted techniques including the missing or insufficient equipment of sanitation infrastructure (Hardoy und Pandiella 2009). These settlements and its inhabitants are quite often not only exposed to natural hazards, but also to diseases because people are forced to live in neighbourhoods where due to their informal status water supply, sanitation and health service infrastructure does not exist leading to an increase of water and sanitation related disease vectors (Hardoy and Pandiella, 2009, 212).

In Europe but also in Northern America the implication of inner-urban dynamics might develop somewhat different. Many old-industrialised cities show processes of population decline. Most notably, aged industrial countries and the post-socialist countries of Eastern Europe show high number of declining cities, which are by some defined as "shrinking cities" (e.g. Kabisch et al., 2004; Oswalt and Rieniets, 2006). These cities are characterized by deindustrialisation, suburbanisation and its urban consequences of vacancy and demolition (Kabisch and Haase, 2009). It is yet an open question which consequences these shrinkage processes may have with regard to vulnerability patterns. However, shrinking urban areas seem to be characterized by a decrease of exposure to water-related natural hazards as less people, economic stocks and increasingly also infrastructure is exposed to environmental hazards and risks. However, with such urban areas new challenges may arise that might reveal new vulnerabilities. First, such cities are most often defined by an aging population, which may be vulnerable to environmental risks and hazards. Second, the loss of population may also challenge the overall financial strength and governmental service provision as well as existing voluntary disasters management systems (e.g. local fire brigades) and other adaptive systems.

4.2.2 Research needs with regard to urban dynamics, risks and vulnerabilities

In light of the three outlined processes contributing to an increase of risks and vulnerabilities of and in urban areas, future research in this application area should focus in a general sense on the question of how to integrate social scientific and urban studies oriented research lines with rather natural scientific approaches of downscaling and specifying the consequences of climate change.

Particularly in so-called developing countries cities are in many cases rapidly growing resulting in an increasing vulnerability of people, infrastructures and buildings to environmental risks and hazards. In other areas of the world cities are shrinking and declining resulting in vacancy and demolition and a possibly reduced exposure of people and buildings to water-related natural hazards. Currently most of the research on the mentioned urban dynamics is focusing on either rapidly evolving mega-cities and how risk are co-produced through their very growth or on how to adapt to processes of shrinkage and decline. With regard to the latter phenomenon hardly any thorough analysis exists on how shrinkage and the emergence of vulnerable conditions are interlinked. Therefore an overarching approach is necessary, which would allow the comparison of "vulnerability dynamics" of rapidly evolving mega-cities and fast shrinking urban areas. There is a need to better understand the underlying processes and structures and how they influence and define the emergence of vulnerability and its patterns.

A second challenge relates to the integration of so-called "endpoint" and "contextual" approaches to vulnerabilities (cf. also O'Brien et al., 2007). While both approaches to vulnerability are well established in their respective scholarly area, the integration of both is still not yet satisfyingly achieved, particularly not on the level of urban areas. The integration of the before mentioned approaches of outcome and contextual vulnerability from two different scientific communities (i.e. climate change and disaster and risk research) appears particularly relevant as it allows the analysis of current and existing vulnerabilities as well as future trends. A thorough examination of this kind would need the interaction between at least two different research communities, that is scholars conducting risks and vulnerability research in line with the climate change community's approaches (e.g. IPCC, 2007) and scholars doing research in line with social science based urban vulnerability research.

4.3 Urban adaptation challenges

The question of how to adapt urban areas to global environmental change is a quite recent issue. There is hardly any agreed upon knowledge available how such a process should be governed and/or steered (Görg, 2010; Kuhlicke and Kruse, 2009). If at all, there seems to be a certain consensus that the adaptation efforts to global environmental change impacts require different types of strategies and responses than traditional adaptation efforts: "Coping with global environmental change is therefore a long-term and far more costly challenge, which requires different ways of thinking and acting" (Simon, 2007, 77). This section therefore elaborates on some of the challenges associated with the task of adaptation urban areas.

4.3.1 Governing uncertainties in downs-scaling global circulation models

A first adaptation challenge arises from the intersection of downscaling global circulation models to the regional or even to the local level with urban policy making scales and structures. While the technical and scientific challenges involved in assessing the impacts of climate change on urban areas are enormous (Wilby et al., 2008), if anything, the institutional challenges involved in using that science for policy making and the development of adaptation options are even greater (Demeritt, 2006; Dessai, 2009; Hall, 2007). As well as organizational issues like resource constraints and heterogeneous bureaucratic cultures within government departments and their delivery partners, there are also fundamental normative challenges about how the cultural values underpinning any risk appraisal or risk-based prioritisation should be informed by, and communicated to, stakeholders and the general public. These socio-cultural factors often shape the use of risk appraisal in different risk domains and organisational settings (Beck, 2009; Demeritt, 2006).

In different political contexts, scientific uncertainties about climate change are alternatively amplified to deny the need for any action (McCright and Dunlap, 2003), mobilized as a rationale for immediate precautionary action (Stern, 2006) or framed as something to be resolved through further research (Shackley and Wynne, 1996). In general there are currently two approaches discussed: There is, first, the “predict-then-act approach” which is based on the assumption that further quantification of uncertainties and more accuracy and precision in the assessments of future climate change are necessary to develop effective adaptation strategies. This view mostly reflects the classical understanding of science as a “provider of certainty”; a view which is deeply influenced by a more general, modernist confidence in the power of reason and technology to overcome nature (Marjolein et al., 2002). Yet, such a view is considered by many scholars as being problematic, since the uncertainties are too profound both on the side of the natural system as well as the societal system and how they mutually influence each other, to simply hope that a more accurate prediction would be possible. The consequences of “predict-then-act” approach may hence be mal-adaptation (Hall, 2007). Therefore, another attempt, the “robust-decision-making” approach is gaining prevalence. It argues that it is more promising to generate policies that are insensitive to the inaccuracy of predictions about an inherently uncertain future (Dessai, 2009; Dessai and Hulme, 2007; Dessai et al., 2009; Lempert et al., 2004; Morgan, 2003). Thus, instead of improving the predictive power of science, it emphasizes the resiliency of policy to climate and other changes in the prevailing boundary conditions of a system.

To give just one example: The question of how to adapt new and existing buildings to climate change is not easy as long as the uncertainties are high with regard to projecting the consequences. Therefore “mechanisms for incorporating uncertain information on future climates” need to be further developed and specified not only in a very general sense but also with regard to the building design (Lisø et al., 2003; Sanders and Phillipson, 2003). There is need for information and research, both with respect to sensitivities in the build environment and technical solutions to climate changes impacts on buildings (Lisø et al., 2003, 208).

4.3.2 The uneven distribution of adaptive capacities

A second adaptation challenge is arising from the empirical observation that adaptive capacities are unevenly distributed among different actors, be they governmental, administrative or private; they vary considerably among regions, countries, and socio-economic groups. There is consensus that those groups considered as most vulnerable seldom have an influential voice with regard to how to govern and steer adaptation (e.g. Hardoy und Pandiella 2009, 212).

Particularly on the urban level the challenge is arising that local governments quite often do not have the resources to efficiently address the impacts of climate change. Indeed, local authorities are often overburdened with tasks related to cope with climate change impacts as these are only one part of the bouquet of services they have to deliver. "Very often, this is mainly true for developing countries, local authorities lack the skills, capacities, and human and financial resources to efficiently tackle with the impacts of climate change on the community" (Laukkonen et al., 2009, 288; cited in; Satterthwaite et al., 2007).

Apart from the lack of missing resources and capacities of local governments, large urban and highly dynamic urban areas are difficult to govern and steer per se. Some scholars therefore argue that such areas are defined by a "loss of formal governability and control" (Kraas 2007, 80), on the one side due to the lack of capacities but also the nature of unpredictable and diverse self-regulatory processes. Particularly in megacities effective conventional governance is no longer taking place. They are defined by inadequate or non-existing land-use control, loss of administrative capacities, weak political-administrative decision-making. These processes are going hand in hand with a growth of informal settlement structure with all its implications (Kraas 2007, 81).

4.3.3 Research needs with regard to urban adaptation

While the technical and scientific challenges involved in assessing the impacts of climate change on urban areas are enormous the institutional challenges involved in using that science for policy making and the development of urban adaptation options are even greater. Therefore a better understanding of the interplay of science and policy is crucial in this respect. There is a need to address and understand the institutional challenges in using that climate science for policy making and the development of adaptation options on the urban level. While there exist some policy-oriented suggestions, such as resilience-based policies and/or adaptive management strategies, there is a lack of a more empirically based understanding of how uncertainties are framed and contested and how those institutional processes of transferring science to policy inform the development of adaptation strategies. Comparatively little work has been done to think through the practical and institutional implications of the above mentioned uncertainties for decision-making processes on the urban level.

4.4 Evaluation of the application area

1. Gaps in scientific knowledge and potential to achieve scientific breakthroughs

The topics for future research proposed are of global relevance and need to integrate different disciplinary approaches. Thereby, the topic of ‘shrinking cities’ has not sufficiently been explored in general but also with regard to risk and adaptation. This topic appears as highly relevant since the risk and vulnerability literature is usually focusing on the negative consequences of rapidly developing urban areas (see above). There is hardly any substantial literature dealing with the negative consequences of a declining or shrinking urban system and how these processes relate to the production of risky and vulnerable conditions (for an exception with regard to infrastructure cf. Moss, 2008). By contrasting rapidly growing and shrinking urban areas and by integrating the climate change community, a true advantage will be generated. Furthermore, to our knowledge there exists no larger international program addressing the research project as outlined above. Apparently, the research project needs to be interdisciplinary in its setup.

2. Science-policy interplay

Many urban areas are currently struggling with the challenges outlined above. The policy problem is highly tangible and although challenging, it is important that a respective research program to be developed is accomplishable within a limited time frame. Policy-maker, practitioners as well as authorities and decision-makers and other stakeholders (e.g. NGOs) play a central role as the inherent uncertainties outlined above demand for a trans-disciplinary and policy orientated research design.

3. Relevance of international policy problem

Policy problems outlined above have been identified relatively recently and it is expected that they gain relevance on the policy agenda as many cities and urban regions are currently developing strategies to reduce their vulnerabilities and to adapt to climate change. It is very likely that the issue will be persistent over the next decades and will becoming even more urgent.

4. Suitability of the program to be implemented in the German scientific community

There exists a critical stock of available expertise in the German research community to address the issues (mega-city research, research on shrinkage and research on the consequences of climate change). The program therefore surely has the potential to strengthen an emerging research and would build its strengths and without duplication of previous programs but rather by developing a complementary perspective.

4.5 Research project outline

In light of the previous overview about the state-of-the art and the outlined research needs this section gives a more specified idea about how a possible research project should be set up. In a first step the general implications are outlined against the background of the previous argument; in a second step the research design is specified, and, thirdly, the relevance of the overall research approach is evaluated. A potential title for a research project could be as follows: “Shrinking and growing: Comparing urban dynamics and its consequences for urban vulnerabilities and adaptation strategies”

The problems with quantifying uncertainties and developing more accurate assessments of future climate change reveal that future research should pay more attention to the question whether to concentrate on the resiliency and robustness of policies, instruments and measures policies that are insensitive to the accuracy of predictions. Research should pay particular attention on how uncertainties are framed and contested and how those institutional processes of transferring science to policy inform the development of adaptation strategies.

The research will integrate expertise from the following disciplines: urban studies, sociology, geography, urban planning and design, hydrology, economics, engineering and climate change modelling. It should to the extent possible adopt a wide geographical distribution of cities (case studies) representative for different urban development patterns with particular attention to rapidly growing cities located in the south and shrinking cities in the north. The research should go well beyond the traditional combination of scientific disciplines exploring the interface between science and the public.

To address the mentioned challenges an inter- and trans-disciplinary research design appears as adequate. While urban studies, for instance, have traditionally been dominated by social scientists and perspectives that have focused on human activity and use of the environment, climate change scholars of focused on better understanding past and projecting future climatic dynamics. The observed complexity and inter-linkages demand for inter- and trans-disciplinary, as well as a intercultural research design. In light of the uncertainties involved in both the projection of future development but also in the decision-making process a multi-stakeholder-oriented and trans-disciplinary research approach seems particular promising. There is a need for generating knowledge based on fundamental analyses and explanations, but also for the creation of applied knowledge for prediction, orientation and decision-making. The regional focus should allow a contrasting research design, which means it should focus on rapidly growing urban areas possibly exposed to severe consequences of climate change (e.g. sea level rise or water shortage) as well as on shrinking cities. In the following a possible research project is specified.

The project should either be a large-scale project or split up in different smaller research projects focusing on well selected case-studies in representative urban areas. In the latter case, the single research projects should be accompanied by an overarching project coordinating and integrating the thematic focus of the other research projects.

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5 Application area: Vulnerability of complex systems of critical infrastructures, society and environment

Against the background of the prognosis of the Intergovernmental Panel on Climate Change (IPCC, 2007) as well as the Stern Report (Stern, 2007), whereby extreme weather events are likely to increase in terms of magnitude and frequency, the set of problems associated with the high dependency of society as a whole and the economy in particular on Critical Infrastructures (CIS) are challenging for both, researchers and decision makers. Recent natural hazard events such as Cyclone Lothar in 1999, Thorsten in 2005 (Bundesnetzagentur, 2006) and Kyrill in 2007, as well as the heat wave in summer 2003 (von Hauff and Kluth, 2006), have drastically shown, how vulnerable highly industrialized countries such as Germany are to natural extreme events. In particular their high dependence on CIS played a key role.

CIS are those governmental and private organizations and facilities by which essential services are supplied. These services include food, water, public health services, energy, transport, information and communication, and waste removal and disposal. The failure of CIS can lead to problems of national security, basic supply service and other severe consequences (BMI 2008). Systems and sub-systems of CIS are at risk worldwide not only because of the growing frequency of extreme events of natural causes, but also because they are increasingly vulnerable to local disturbances. This is, in part, due to the strong reliance of CIS on each other, which may turn a local disturbance into a large-scale failure via cascading events that have catastrophic consequences on society as a whole. For instance, the normal operation of water, telecommunications, transportation, and banking systems is maintained only if there is a steady supply of electric energy. However, the generation and delivery of electric power cannot be ensured without the provision of fuel, water, and various telecommunications and computer services (Bigger et al., 2009). Assessing vulnerabilities and developing solutions for governing the manifold interdependencies of CIS is complex by nature, especially because nowadays CIS are configured in a web of 'system of systems' that has no single owner or operator (IRGC, 2010). Additionally, the gap between increasing dependency on CIS of societies in developed countries and particularly in urban centers and the lack of knowledge on the vulnerabilities of CIS pose a threat (Boin und McConnell, 2007).The major research question is, what are the implications of extreme events and climate change for society in general and civil protection in particular with regard to adaptation challenges and opportunities of CIS (Lauwe and Riegel, 2008; Birkmann and Krings, 2008)?

In the following future challenges regarding ensuring CIS resilience and future research needs are going to be discussed. Thereafter an evaluation of this application area against the already mentioned criteria in chapter 3 and 4 will be conducted to conclude with a project proposal.

5.1 Scopus analysis

To assess the current state of development in this field of research, a bibliometric analysis of publications using SCOPUS database has been conducted for the time period of the past 10 years. For the analysis the combination of the key words "critical infrastructure and vulnerability" were chosen. The results show the number of publication in peer reviewed journals in the search space of 'articles', 'proceedings papers', 'reviews', and 'editorial material' that included the 'search terms" in abstract, titles or key-words.

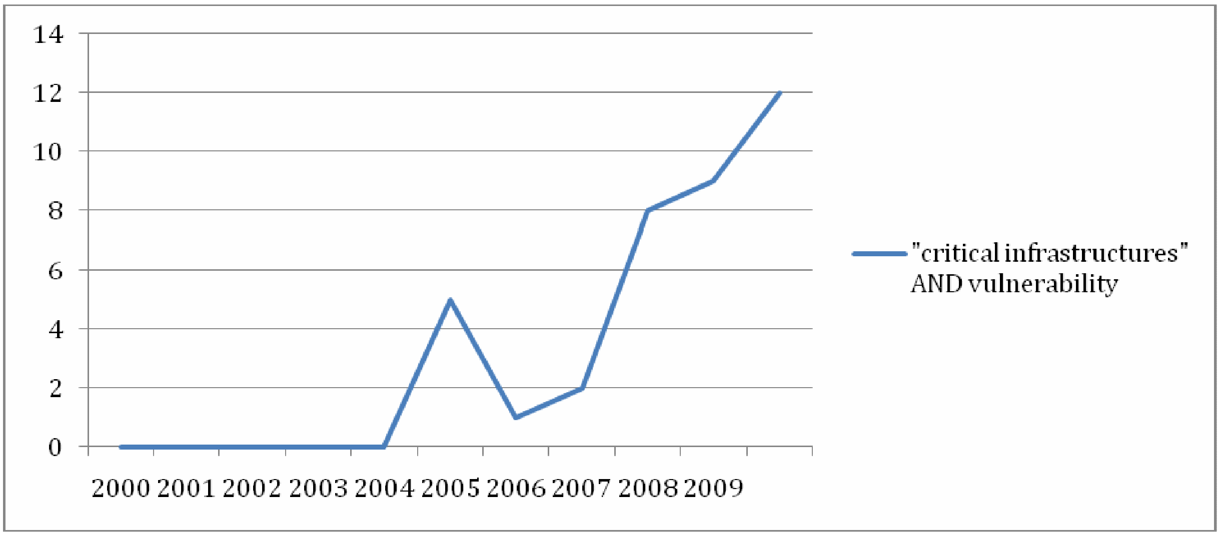

Figure 4: Bibliometric Analysis using the key words "Critical Infrastructures" and "vulnerability"

Figure 4 shows that the number of publications using these key words has increased from 2 publications per year in 2004 to 12 per year in 2009, which is a significant increase and shows that the relevance of CIS in vulnerability research gradually increases but is still very high in terms of publication output. The implications of these trends will be outlines in the following chapters.

5.2 Coupled systems of critical infrastructures, society and environment in the context of water related fast onset and creeping hazards

CIS are due to their importance for the functioning of societal processes and their vulnerabilities with respect to climate change and extreme natural hazard impact well recognized in the Strategy for Adaptation to Climate Change (BMU, 2008a). CIS are impacted by fast onset and extreme events in various ways. As with other types of man-made hazards such as terror attacks or accidents, CIS components can be directly damaged and affected by extreme water related weather events. A prominent example from Germany is the electricity blackout in the „Münsterland“ caused by a snow storm in winter 2007, which led to emergency situations for the population due to temperatures below zero (Birkmann and Krings, 2008). On the other side, the functionality of CIS can be disturbed also by long-term and slow onset environmental change; e.g. the heat wave in 2003 reduced the water availability for power plant cooling systems, which resulted in lower levels of electricity availability (Birkmann and Krings, 2008).

At the same time environmental change and extreme water related hazards as a consequence of climate change will alter the demand for CIS services. Their increase or decline is embedded into overall processes of societal transformation (technological innovation, resource utilization and distribution, consumption patterns, and habits of way of life) and is socially very differentiated. Although, social groups such as elderly, chronically ill, and other disadvantaged groups are the same way exposed to extreme events, such as heat waves or floods, they might suffer more harm than others requiring changes in the utility and dependency on CIS services (see EU commission DG-Health, 2007; BMU, 2008a: 18; Koppe et al., 2004).

To conclude, when studying coupling effects at the interface between CIS, society and environment it is necessary to investigate on the one side how climate change and water related stress affect the performance and availability of CIS services and on the other side how demand and dependency patterns change in the course of sudden extreme events and long-term changes in the environmental system hereto referred as creeping events. The heat wave in 2003 has demonstrated the conflict between an increase in the demand for electricity and the decline of the electricity availability (see BMU 2008a).

The impact and relationship of direct and suddenly occurring extreme events as well as long-term creeping change of ecosystem services on coupled CIS and their effects for human systems is schematically shown in figure 5.

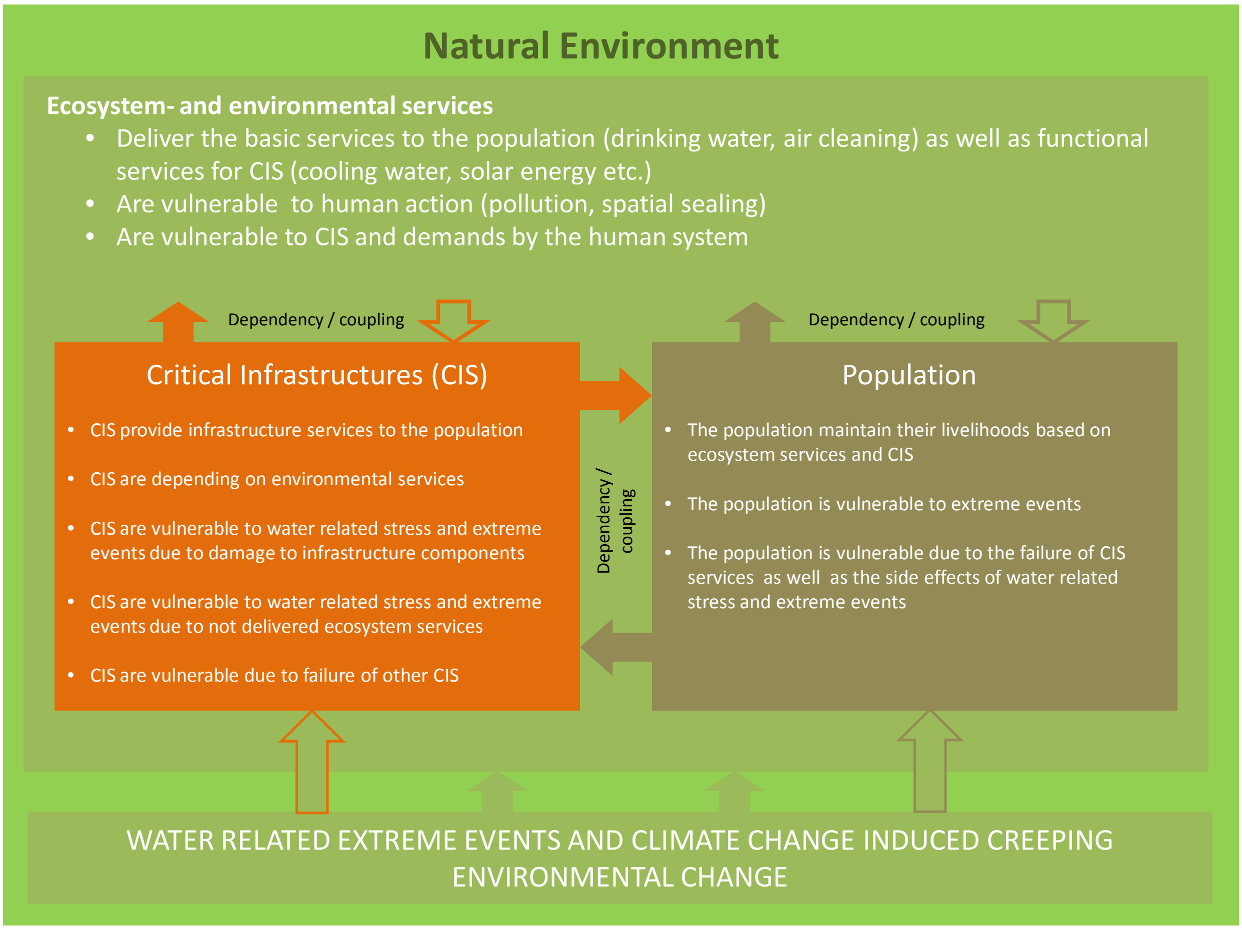

Figure 5: Impact relationship between population, CIS and water related extreme events related to global climate change. Source: adapted from Birkmann and Krings 2008

5.3 Research needs and gaps

Future research needs to address in an integrated manner the coupled social, environmental and technical system, in which CIS are embedded by focusing on the interplay between vulnerability patterns and the response activities of the population related to water related sudden and slow onset events. Based on the literature on CIS analyzed, most of research on CIS has been carried out in the United States of America focusing on CIS vulnerabilities related to man-made hazards, such as terror attacks, accidents and CIS systems inherent fragilities. Major research topics on failure propagation, transnational CIS vulnerability, quantifying infrastructure interdependencies and conducting CIS reliability modeling and analysis could be identified (see Auerwald et al., 2005; van der Vleuten et al., 2010; Panzieri and Setola, 2008; Sultana and Chen, 2009; Apostolakis and Lemon, 2005; Ezell, B., 2007; Gheorghe, A., & D. Vamanu, 2004). Although there has been considerable research on CIS conducted it is restricted only to man-made hazards which have different impact patterns then fast onset and creeping water related hazards of natural origin due to different functions of spatial coverage, intensity and propagation. In addition, the coupling perspective between CIS and social and environmental systems is missing in current CIS research. It focuses solely on CIS systems' inner configurations, thus in an isolated manner from environmental and social processes and interdependencies.

With regard to vulnerability of CIS to water related extreme events, recent research has been conducted at UNU-EHS on how to assess the vulnerability of electricity and water supply infrastructures in terms of their likelihood to fail during the course of a flood event. The research aimed at developing a guideline and method of analysing and evaluating the vulnerability of the different single CIS components regarding their exposure, functionality (relevance), technical redundancy and organizational preparedness. In a relative ranking the results were brought together to quantify the level of vulnerability for each of the identified components (BBK, 2009). Although the research focuses on environmental stressors it does not account for impact chains and cascading effects of critical infrastructure failures on other supply networks and the population as well as the economy in highly technical, industrialized and service dependent societies.

Future research needs to focus more on the identification of the links between vulnerability patterns of social-ecological systems and CIS. Since CIS are key for productive systems (.g. agricultural and industrial systems) and because they utilize and distribute environmental and processed resources, their function depends not solely on technical capacities but also on quality standards of environmental conditions and services. The significant reduction of the capacity of power plants during the heat wave 2003 on the river Neckar was not solely caused by technical limits; rather the water temperature of the Necker reached a critical value that restricted the further warming of these rivers by power plants and their “cooling processes”. Consequently, the vulnerability of CIS and their services in the context of water related hazards is linked with complex coupling processes of social-ecological and socio-techno-ecological systems. These interdependencies and interactions often have been overlooked in recent risk assessments. In many assessment approaches solely the physical exposure of CIS is taken into consideration.

Thus, new challenges also arise for governing CIS under conditions of increasing water related disaster risks and climate change impacts. And how does the security of CIS services can be guaranteed under conditions of transformations of CIS governance systems, such as trends of deregulation and privatization of CIS service provision (see De Bruijne, M. und M. van Eeten, 2007). Also in the context of these transformations, how to develop protection goals and standards for threats that are largely unknown?

Thus, the following future research topics are proposed that need be dealt with in an integrated manner. In accordance to the Strategy for Adaptation to Climate Change, CIS shall be addressed in the following sectors: public health, emergency services, water, energy, finance, transport and logistics. Considering these sectors and their different characteristics, research has to be carried with the following objectives:

- Development of a conceptual framework to capture the vulnerability of complex, coupled systems and interdependencies between CIS, society and environment and potential cascading effects.
- Conduction of a comparative analysis of types of man-made and water related fast and slow onset hazards and their effects on different CIS.
- Evaluation of the influences of increasing deregulation and privatization of CIS services on their overall vulnerability and adaptive capacity and related effects to society and development of recommendation for risk and adaptive governance of CIS.
- Development of vulnerability assessment criteria and protection standards for resilient CIS.
- Evaluation of opportunities, challenges and limitations of the adaptability of CIS and the role of organizational and technical instruments for adaptation.
- Evaluation of future and innovative CIS such as “smart grids” (electricity) regarding their vulnerability and resilience in the context of CIS-interdependencies and coupling effects of CIS failures.

5.4 Evaluation of the application area

a) Potential to achieve scientific breakthroughs

The research challenges outlined in the previous chapter have high potential to achieve scientific breakthrough because on the one hand only little research has been conducted on water related risk research of CIS linked to social-ecological coupled systems allowing for fast progress in generating new knowledge. On the other hand, substantial CIS research related to man-made hazards has been conducted that can provide significant input for advancing in water CIS research related to water related risks and vulnerabilities.

b) Science-policy interplay

CIS research deals with questions of service delivery capacities of mostly governmental but also private facilities whose tasks are to sustain human security and well-being of the economy, the environment and at large citizens. In this respect the protection of CIS against emerging threats such as water related fast and slow onset hazards are sovereign duties, which is critical for governments' performance of welfare provisions. Thus, conducting research and developing solutions how to govern CIS requires from the beginning the involvement of governmental and no-governmental organizations working in specific CIS sectors and closely together with CIS operators, authorities involved in civil and environmental protection and policy and finally groups of end-users who depend on CIS services: Taking the example of the risk governance framework of Renn (2008) and the IRGC (2005) stakeholder involvement is required for all governance phases; starting with problem framing and continuing with vulnerability assessment and the evaluation and development of management options.

c) Relevance of international policy problem

Systems and sub-systems of CIS are at risk worldwide not only because of the growing risks worldwide associated with water related extreme events, but also because CIS are increasingly vulnerable to local disturbances. This is, in part, due to the strong reliance of CIS on each other, and a result of globalization which led to worldwide economic integration and increasing interconnectivity of CIS. Consequently, local disturbance are turned into a large-scale failure via cascading events that have catastrophic consequences on society as a whole.

d) Suitability of the program to be implemented in the German and European scientific community

Germany bears a great potential to form a multi-disciplinary group of scientists representing the complex nature of the application area. Apart from research domains related to the social-ecological dimension of CIS, research capacity of groups in Germany particularly focusing on CIS is limited. Up-to-date research on CIS has been or is being carried out by PIK, UNU-EHS, DLR, CEDIM and the IRGC. Respective research programmes are still in its infancy regarding capturing the entire dimension of vulnerability of complex systems of CIS, society and the environment.

5.5 Project outline

A research project shall focus on the development of a by CIS operators and CIS policy makers well accepted and theory based conceptual framework for assessing the vulnerability of complex and coupled systems of CIS, society and the environment.

For this and for the development of a classification scheme of the different vulnerabilities of complex coupled systems of CIS, society and the environment and to conclude with the development of protection goals, standards and best practice governance guidelines for coupled CIS systems, the following three different research components shall be addressed and finally brought together:

(1) Conceptual and empirical applied research shall take into account a multi-hazard perspective since the challenges for governing the vulnerability of complex and coupled systems of CIS, society and the environment are whether and how different hazard types and vulnerability patterns can be accommodated in a multi-hazard resilient CIS approach and how to deal with trade-offs. Thus, the project shall focus on two different threat characteristics: water related fast onset hazards, such as floods and flash floods and slow, creeping onset hazards such as heat waves and sea level rise.

(2) Apart from addressing different threat scenarios (slow and fast onset), the project shall also compare different CIS systems. For their differentiation and selecting a representative sample, research shall be carried out according to the following criteria: Degree of relevance of CIS as service provider for other CIS services (e.g. electric power supply), their function (e.g. provision of health, food) and dependency on natural resources to explore the coupling effects at the interface between CIS, society and the environment.

(3) The above mentioned two research components shall be embedded in an analysis of general framework conditions in which CIS operate and that influence the vulnerability of CIS to water related fast and slow onset hazards. Among others the three most relevant framework conditions that need to be explored are: Trends of privatization and decentralized operation of CIS changing the regulatory culture of CIS governance, the increasing challenges to govern the complexity of CIS global interdependencies, and the innovative development of CIS in terms of new CIS systems such as “Smart Grids” and the ongoing digitalization of CIS operations.

In order to be scientifically sound, a case study based research design should be developed that allows for a systematic global comparison of the vulnerability of complex coupled systems of CIS, society and the environment. But depending on project proposal requirements case studies can also focus on specific geographical areas of interest. Nevertheless, the requirement to design research activities that take into account CIS relevant political, economic and environmental system boundaries shall not be neglected.

Since water related CIS governance is considered as an important dimension of social-ecological research a trans-disciplinary and multi-disciplinary research consortia composed of researchers and decision makers representing expertise in law and policy, economic, political, social, engineering and natural sciences shall be set up.

5.6 Cited literature

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Quantitative SCOPUS-Analyse (1995 – 2010)

Keywords	Treffer gesamt
governance AND vulnerability	194
governance AND uncertainty	572
"risk management" AND vulnerability	591
vulnerability AND adaptation	1751
vulnerability AND "adaptive management"	53
resilience AND "adaptive management"	141
institutions AND uncertainty	1525
institutions AND indicators	2735
culture AND governance	1207
institutions AND assessment	16431
social-ecological AND governance	68
social-ecological AND water	53
social-ecological AND uncertainty	45
social-ecological AND adaptation	56
"critical infrastructures" AND vulnerability	132

Search Term	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
governance AND vulnerability	0	2	2	0	3	4	10	11	12	15	23	15	27	28	38	4
governance AND uncertainty	3	102	4	10	19	16	16	23	26	25	49	54	71	68	72	14
"risk management" AND vulnerability	4	8	13	11	17	16	15	26	26	56	59	58	64	84	107	27
vulnerability AND adaptation	46	51	66	55	68	100	72	86	108	127	141	154	170	212	214	45
vulnerability AND "adaptive management"	0	1	0	1	1	0	0	0	0	1	5	3	8	13	17	3
resilience AND "adaptive management"	0	1	4	0	19	15	4	5	7	5	6	17	13	15	27	3
institutions AND uncertainty	20	42	42	54	63	53	72	85	106	125	127	150	200	156	193	37
institutions AND indicators	49	92	90	113	113	123	137	158	181	197	234	247	287	305	339	70
culture AND governance	8	21	17	32	52	64	71	71	70	95	122	117	147	125	161	34
institutions AND assessment	319	448	472	608	636	659	863	880	1128	1278	1431	1735	1694	1855	1928	497
social-ecological AND governance	0	0	0	0	0	0	1	3	1	6	6	8	13	10	17	3
social-ecological AND water	0	2	2	1	0	0	0	2	1	2	4	6	4	10	16	3
social-ecological AND uncertainty	0	0	0	0	1	0	1	3	2	0	4	4	12	6	8	4
social-ecological AND adaptation	0	0	1	1	0	4	5	4	1	3	3	5	7	6	12	4
"critical infrastructures" AND vulnerability	0	0	0	0	0	5	1	2	8	9	12	22	20	21	27	5

Web of Knowledge

Search Term	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
urban dynamics AND risk	2	7	13	4	17	20	12	22	38	35	39
urban dynamics AND adaptation		1	2					3	5	5	6
urban dynamics AND vulnerability								4	4	9	4
urban AND environmental risk	59	61	88	82	95	119	110	149	177	211	243
urban AND natural risk	15	16	32	21	39	32	39	52	45	78	77
urban AND adaptation	21	27	26	22	26	33	34	50	68	89	100
urban AND climate change	25	20	31	29	48	51	67	93	138	166	246

Scopus

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Search Term											
urban dynamics AND risk	25	16	22	28	34	30	29	41	69	56	63
urban dynamics AND adaptation	4	3	5	4	5	2	3	6	7	11	10
urban dynamics AND vulnerability		1	3	2	3	3	2	7	8	10	4
urban AND environmental risk	156	208	254	250	260	336	347	430	483	461	481
urban AND natural risk	37	41	62	44	63	63	86	96	90	117	100
urban AND adaptation	86	92	95	107	114	121	146	177	183	209	219
urban AND climate change	84	85	75	92	84	130	154	177	272	239	311

Governance of Transformation

Application area 1: Developing and evaluating infrastructure transformation

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Introduction

In many cities major water supply and sanitation infrastructure development is underway, and more and structurally different developments are needed to meet sustainability requirements. This applies to both cities with an existing urban infrastructure which proved to be non-sustainable in the long-term and to fast growing cities in developing and transition countries where infrastructure development cannot keep pace with the fast growing settlement.

What is lacking are systemic policy, planning and implementation processes that take into account the cultural, socio-economic, political and technological conditions and develop context specific societal (e.g. legal regulations, technical skills, supply and maintenance networks) and technical (physical and climatic conditions) infrastructure. Such processes should build infrastructure systems that are flexible and robust to changes in boundary conditions such as population developments, climatic conditions, functional requirements, financial arrangements, risk management etc. Furthermore a demand exists for methods to analyse the success and failure of the governance processes described above and to assist the transfer of insights.

The problem statement above gives an expert view of problems encountered in the development of water supply and sanitation systems developed by a panel of international experts at the "Future trends and research needs in water management" workshop held at the Institute for Environmental Systems Research (USF) in Osnabruck, Germany, February 3rd and 4th 2010. The problem statement is based on expert judgement and experience and its relation to a scientific field of research is not specified.

The workshop was held as part of a project study commissioned by the German Federal Ministry of Education and Research (BMBF) in order to evaluate water research themes with respect to their potential for scientific breakthroughs, political impact and suitability for the German water community. The aim of this study "Analysis of potentially new themes in water management - future trends and research needs" is to identify promising future research themes and to develop recommendations for a future research programme of the BMBF. For this, the study analyses the international water research and policy landscape and takes stock of recent achievements. In a preliminary assessment the following themes of high political relevance and major research needs and potential have been identified:

1. Adaptation to climate change
2. Food and water – virtual water flows
3. Urbanization and infrastructure
4. Disasters and vulnerability to water related threats
5. Water governance (cross-cutting)
6. Ecosystem water requirements – environmental flows (cross-cutting)

The topic of this report, Developing and Evaluating Infrastructure Transformation is part of what is now called the Governance of Transformation theme. The relevance of this theme is supported by an overall agreement in the February 2010 workshop that major transformations towards sustainability are the key challenge in water resources management in general and for water resource governance in particular. Major structural changes are needed in all domains of the water sector but it is by no means evident how they should be governed if they can be governed at all.

This report assesses the merits of this problems description a part of a future research programme of the BMBF on four criteria:

1. Gaps in scientific knowledge and potential to achieve scientific breakthroughs
2. Science-policy interplay
3. Relevance of international policy problem
4. Suitability of the program to be implemented in the German scientific community

1 Approach and Method

In order to address the four issues in this report we will use the following approaches.

Gaps in scientific knowledge and potential to achieve scientific breakthroughs
This criterion is specifies in more detail by the following sub criteria:

- Gaps in highly relevant fields with little indication of any large international program addressing them.
- Expected outcomes have the potential to open up an internationally visible and innovative research field.
- Interdisciplinary approach needed to achieve scientific breakthroughs (preferably comprising collaboration between social and natural sciences)
- Barriers to be overcome are judged to be surmountable in a research programme

We first indentify possible gaps in knowledge in the scientific literature using the Scopus data base and a pertinent set of keyword. Second we use the keyword 'research program' in addition to our set of topical keywords to identify relevant international research programs using Google Search. In addition these analysis will give us some clues on relevant scientific disciplines that address , started to address or have the potential to address the topic of developing and evaluating infrastructure transformation in water supply and sanitation. Next we will use this more substantive information to address the issues of internationally visibility, interdisciplinary and the required scope of a research programme that surmounts the topic raised.

Science-policy interplay
This criterion is specified along the following dimensions:

- Link to relevant stakeholders, efficiency and effectiveness of implementation, potential of a programme to have a real impact
- Policy problem is tangible enough that a research program can provide meaningful policy advice within a limited time frame.
- International relevance but scope for German or European policy to play a leading role
- Ongoing - developing policy process to which the program can be linked

We first identified relevant stakeholder in the field of urban water supply and sanitation. From their organizations and activities, especially in developing countries, we judged the potential contribution of a research program and the required time horizon. In addition this reconnaissance gives us some insights into the possible scope of German and European involvement in this research theme and ongoing-developing processes to which the program can be linked.

Relevance of international policy problem
To judge the relevance of the policy issue, the following criteria are relevant:

· Policy problem is emergent, has been identified more recently and is currently
· moving higher on the policy agenda.
· Most likely to be persistent over the next decade and become even more urgent.

We used general information on the development of the policy issues over the last decades to analyse and judge it relevance

Suitability of the program to be implemented in the German scientific community

The suitability of the envisioned program to be implemented in the German scientific community as evaluated based on:

- Critical stock of available expertise in the German research community to address the issues
- Program has the potential to strengthen an emerging research community (e.g. water governance)
- Build in strengths and achievements in the German research community without duplication of previous programs
- Support of developing collaborations between communities that have failed to do so in the past.

We based our analysis on the information on relevant scientific institutions related to the bodies of literature identified in the Scopus search. Furthermore we used the key-word of the Scopus search to identify current and recent research programs. Through this analysis we also gained some insight in collaborating partners within the Germans and European scientific community.

2 Results

2.1 Gaps in scientific knowledge and potential to achieve scientific breakthroughs

To identify the amount of scientific work invested in the topic of developing and evaluating infrastructure transformation for water supply and sanitation we used a converging approach. First we separated the research into development from research on evaluation (level 1 key word). For both fields of research we started with these more general issues and then focussed on transformation (level 2 key word) and further converged onto infrastructure (level 3 key word) and then specified infrastructure into water supply and sanitation (level 4 key word). Finally we separated urban from rural (level 5 key words).

While infrastructure and sanitation are clearly defined concepts that will not cause much confusion in literature searches, the concept of transformation is ill defined and has different meanings and definitions in different bodies of literature. Timmermans (Timmermans, et al. 2008) gives an overview of the scientific use of the concepts of transformation in scientific fields ranching from the natural sciences to the social sciences. Table 1 give a summary of these concepts. From this table we use transformation, transition, innovation and structural change as our key words.

A further specification of key words related to developing and evaluating infrastructure transformation concerns the terms developing and evaluating. From the problem description it appears that developing is taken as a synonym or container concept for governance, policy development, management and implementation. We use governance, policy, management and implementation as our key words and add resilience, adaptive and flexible, as these terms are often used to reframe transformation into an attribute of the infrastructure itself.

The term evaluation is related to methods to analyse the success and failure of the governance processes described above and to assist the transfer of insights. We feel that the term institutional transplantation (de Jong, et al. 2002) adequately describes the process of transplanting successful arrangements from one country or culture to the other while evaluating both success in the country of origin and potential success in the receiving country or culture. We therefore use institutional transplantation as a key word in addition to evaluation.

Furthermore we limited our search field to the sub areas Agricultural and Biological Sciences-**AGRI**, Business, Management and Accounting-**BUSI,** Decision Sciences-**DECI**, Economics, Econometrics and Finance-**ECON,** Energy-**ENER**, Engineering-**ENGI,** Environmental Science-**ENVI,** Psychology-**PSYC**, Social Sciences-**SOCI** and Multidisciplinary-**MULT** while leaving out Arts and Humanities-**ARTS** Biochemistry, Genetics and Molecular Biology-**BIOC,** Chemical Engineering-**CENG,** Chemistry-**CHEM,** Computer Science-**COMP,** Earth and Planetary Sciences-**EART**, Immunology and Microbiology-**IMMU,** Materials Science-**MATE,** Mathematics-**MATH**, Medicine-**MEDI**, Neuroscience-**NEUR**, Nursing-**NURS,** Pharmacology, Toxicology and Pharmaceutics-**PHAR,** Physics and Astronomy-**PHYS,** Veterinary-**VETE**, Dentistry-**DENT and** Health Professions-**HEAL**. In addition we limited our search to the period 2000 – April 2010.

Table 1 Concepts expressing structural change in different scientific fields

Scientific field	**Concept used for structural change**
Natural sciences	transition
Organizational sciences	transition
Policy sciences	Policy punctuations, policy innovations, radical change
Economics	Structural change, system innovations, transformation, transition (heterodox), transition (state economic systems)
sociology	Transition, transformation

The results of this search are presented in the table of Annex 1. From this analysis some relevant conclusions on the gaps in scientific knowledge related to developing and evaluating infrastructure transformation can be arrived at:

Development

- A large body of literature related to the governance of transformations exists. Further inspection of these bodies of literature learned that these are mainly from the social and environmental sciences and from engineering. Publications from engineering cover a wide range of issues of which some are relevant to the current topic while others are less relevant.

- The amount of the governance of transformation literature related to infrastructure is limited to a few hundreds of publications. Again these publications are mainly in the field of social and environmental sciences and from engineering. Again publications from engineering are not always relevant.

- A focus on the governance of transformation of water supply and sanitation infrastructure is virtually absent in the scientific literature.

- A further focus on urban development, where problems related to water supply and sanitation are prominent, is only addressed in a single pioneering publication

Evaluation

- A large body of literature addresses innovation, as expected. However, the focus on infrastructure is limited and a focus on water supply and sanitation is absent. Furthermore this is a broad field with applications in even more or all fields of science and in our opinion does not cover its meaning in the topic of this report

- In the field of institutional transplantation, which we think adequately covers " methods to analyse the success and failure of the governance processes and to assist the transfer of insights", of 42 publications 1 cover infrastructure

Relevant conclusion for the topic application area developing and evaluating infrastructure transformation is that a gap of scientific knowledge exists in the translation of governance of transformation to infrastructures and more specific water supply and sanitation in urban areas. A research program surmounting this gab in scientific knowledge is thus necessarily interdisciplinary and needs to build a bridge from the social to the natural and engineering sciences. Expected outcomes have the potential to open up an internationally visible and innovative research field. The availability of a limited number of pioneering publication in this field shows that such an endeavour is feasible. Especially when organized as a research program it seems feasible to surmount the progress made by individual pioneering researchers.

2.2 Science-policy interplay

In Europe, urban water supply and sanitation was mainly developed under the responsibility of municipalities. This institutional context is highly correlated with the mainstream technology, piped water and sewerage systems, and framing of the problem in terms of hygiene and health (Geels 2006). Increasingly municipal responsibilities are transferred to autonomous and quasi-autonomous non-governmental organization like water supply companies while sewerage (sanitation) remained largely a municipal task. Often these organizations have their own professional and industrial associations. Currently some of these companies develop into multinationals managing and developing water supply and sewerage systems worldwide. For example Suez-environmental of which the German Eurawasser is as an affiliation.

Table 2 Stakeholders and partner in the policy-science interface

Stakeholder categories	Examples
Citizens	As consumers or partners in community initiatives
Local and regional administrations	Municipalities, water authorities, state governments (Lander)
Local and regional Water supply and wastewater companies	(quasi-)autonomous non-governmental organization like Gelsenwasser AG, Berliner Wasserbetriebe and their international counterparts
Multinational water and waste industry	Suez-environment- Eurawasser
National governments	federal government, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)
European Union	Urban Waste Water Treatment Directive (91/271/EEC) of 21 May 1991, The Drinking Water Directive (98/83/EC) of 3 November 1998, ACP-EU Water facility
United nations	WHO, UNESCO, Water Decades
Professional and industrial associations	Association of Electricity and Water Utilities BDEW, VKU (association of municipal utilities), DWA (professional association for water and sanitation) etc.
Universities and knowledge institutes	civil engineering, sanitary engineering, social and policy science departments of universities,
Consultants	Fichtner Group, DIWI etc.

An interaction with this development a consultancy and supply sector emerged that covered water purification, waste water treatment, piping and sewerage systems etc. Furthermore sanitary engineering became part of the curricula and research agenda's of mainly technical universities and knowledge institutes. In relation to water supply and sanitation activities in developing countries, public and users participation became an issue and shifted water supply and sanitation issues onto the agenda of the social sciences.

While governmental involvements in the development and management of water supply and sanitation declined, governmental involvement in setting drinking water standards and standards for sewerage collection and treatment increased and are currently addressed at the European and Global level. Especially UN institutions are active in this field. For example the World Health Organization setting standards for the quality and quantity of drinking water. UN initiatives like the International Decade for Clean Drinking Water (1981-1990) and the current 2005 to 2015 International Decade for Action – Water for Life manage to keep water supply and sanitation issues high on the global agenda. Especially these global initiatives create a supportive climate for meaningful science –policy connections. Similarly many countries focused on water supply and sanitation issues in their international cooperation programs. Multinational water corporations constitute both interesting object of research and partners for implementation.

Table 2 shows a rich variety of relevant stakeholders, objects of research and partners in a research program. Cooperation with these partners can improve the efficiency and effectiveness of a potential of a research programme on developing and evaluating infrastructure transformation to have a real impact. Careful selection of partners and a clear focus on transformation is however a necessity; many organizations in Table 1 have established positions and interest in the sector and transformation is not their core business. Especially EU, UN and national programs on water supply and sanitation offer ample opportunities to connect a research program to developing policy processes.

2.3 Relevance of international policy problem

From for example the timing of the UN initiated water decades, it becomes clear that the policy problem of urban water supply and sanitation has been identified decades ago but remained high on the policy agenda since. This development indicates that the problem is likely to be persistent over the next decade and become even more urgent. Especially this persistence on the policy agenda calls for a research program focussing on transformation. The literature on societal transitions (Geels 2002; Rip, et al. 1998) advocates the need for new governance arrangement to address this type of persistent problems.

The fact that the policy problem is not emergent, has been identified decades ago and remained on the on the policy agenda, is a strong argument for a research program with specifically focuses on governance approaches addressing transformation, transition and policy innovation. Lacking such approaches, the issue is most likely to be persistent over the next decade and become even more urgent.

2.4 Suitability of the program to be implemented in the German scientific community

In section 3.1 we identified the translation of governance of transformation to infrastructures and more specific water supply and sanitation in urban areas as gab in scientific knowledge. We now use the national origin of the literature on governance of transformation of infrastructure and on governance of transformation water supply and sanitation infrastructure to arrive at some conclusions on the receptiveness of the European and more specific German scientific community for such a program.

From our Scopus analysis it appears that the 337 results up to the key-word infrastructure (Appendix 1) mainly originate from American and European Universities with London School of Economics and ETH Zurich as relevant institutions. Relevant journals are European Planning Studies and Geographische Rundschau. These results indicate that a relevant research community on the governance of the transformation of infrastructures exist within Europe. The evaluation and transplantation of transformation of infrastructures, the European position is stronger while besides the US, Singapore is a relevant country of origin. Relevant institutions in Europe are the Eindhoven University of Technology and Imperial College London. Relevant journals in these fields are international and not connected to Europe or Germany. Publications on institutional transplantation mainly originate from Delft University of Technology and also the single pioneering publication on infrastructures stems from this university.

In conclusion a research base for a program on governance of the transformation of infrastructures exists within Europe. The United Kingdom, Switzerland and The Netherlands are relevant partners while the position of German Universities is this field in not yet standing out. On the broader topic of governance of transformation, within Europe the universities of Manchester and Oxford are relevant partners.

Most of the research programs addressing governance of transformation are related to climate change. For example the US Global Change Research Program, the German Klimzug program and the Dutch Knowledge for Climate program and transitions to sustainable development like the Dutch KSI program.

Some programs focus on infrastructures like the Dutch Transitions and transition paths: the road to a sustainable energy system, the political ecology of infrastructures in three German regions program of the Technische Universität Darmstadt, Germany the International Human Dimension Program On Global Environmental Change which includes some research projects on urban development and Transformation Processes in the Water Sector and the Dutch Next generation Infrastructures research program. The Australian National Urban Water Governance Program focuses on urban areas but addresses the issue of water supply and sanitation under de broader heading of water sensitive cities (for URL's see Annex 2)

From the above we conclude that currently no research program specifically focusing on developing and evaluating urban water supply and sanitation infrastructure transformation does exist. Some research program share a focus on governance of transformation and water management. These programs however take a broader scope by addressing water in urban areas as an integrated issue (de Graaf, et al. 2009). These program come close to what is intended with this research topic and their integrated approach needs to be taken serious.

3 Some research ideas

3.1 Socio-ecological and Socio-technical Systems

The transformation of water supply and sanitation infrastructure can and are both studied as socio-technical systems and as socio-ecological systems (SES). They are socio-technical systems (STS) because of the embedednes in and interaction of their technology in a wider social environment. They are SES because water supply and sanitation systems are endogenous to the ecosystems from which they abstract resources (Toonen 2010; Ostrom 2009). This combination of SES and STS characteristics distinguishes urban water supply and sanitation from other infrastructure, which are largely studied ad STS.

The most prominent theoretical concept used to analyze and describe socio-technical transitions is the multi-level perspective (Geels 2002; Rip, et al. 1998; Kemp 1994; Schot, et al. 1994). The multi-level perspective distinguishes three heuristic analytical concepts: niche innovations, socio-technical regimes and socio-technical landscape. The socio-technical regime refers to cognitive routines shared by an engineering community, scientists, users, policy makers and special interest groups. In technological niches, radical novelties emerge while niches act as 'incubation rooms' protecting novelties from the scrutiny of existing markets (Kemp, et al. 1998; Schot 1998). The socio-technical landscape forms an exogenous environment of macro-economic development, deep cultural patterns and macro political developments beyond the direct influence of niche and regime actors. Using these three concepts, transitions come about through interaction between processes at these three levels.

SESs are composed of multiple subsystems and internal variables within these subsystems at multiple levels. In a complex SES, subsystems are relatively separable but interact to produce outcomes at the SES level, which in turn feed back to affect these subsystems and their components, as well other larger or smaller SESs (Ostrom 2009). Scholars have tended to develop simple theoretical models to analyze aspects of resource problems and to prescribe universal solutions. For example, theoretical predictions of the destruction of natural resources due to the lack of recognized property systems have led to one-size-fits-all recommendations to impose particular policy solutions that frequently fail.

The combination of the STS and SES concept is not only relevant to cover the characteristics of the systems under study, urban water supply and sanitation infrastructure, but also because their combination covers transformation or transition, a long term perspective and governance in relation to sustainable development

3.2 Next generation infrastructures

Modern society is changing rapidly, but our infrastructures are lagging behind. As large scale, complex, capital-intensive systems with long life cycles, they lack the flexibility to adapt to our ever-changing demands. It is important to realise that most traditional infrastructures were not designed as public systems.

Our electricity, gas and telephone networks for instance - which originated in the 19th century - were initially run by private utility companies serving local markets. Because of the public significance of the infrastructure these local grids were gradually connected to each other and put under public control (Arts, et al. 2008).

If we could design our infrastructure systems all over again, what would be the best way to render them more dynamic, more suitable to meet changing future conditions? Basically, this is the central research question of the next generation infrastructure approach.

3.3 Policy entrepreneurs

The importance of policy entrepreneurs as a source of policy innovations, societal transitions and radical change has been recognized since long (Loorbach 2009; Currie, et al. 2008; Loorbach 2007; Roberts 1998; King, et al. 1992; Cohen 1988). In the literature on policy entrepreneurs, Mintrom emphasizes the role of individual policy entrepreneurs in policy innovation (Mintrom 1997). In entrepreneurial design Roberts stresses the extent to which public entrepreneurship derives from collective rather than individual efforts (Roberts 1998). In the realms of governance for sustainable development and societal transitions, this tradition is continued by transition management (Loorbach 2007).

With transition management as a notable exception, research on the role of individuals in transformations or transitions has mainly focussed on description and historical analysis. Transition management assumes that a structure for collective entrepreneurship, namely the so-called transition arena, can be established to facilitate or manage radical change (Loorbach 2007). Within the field of policy entrepreneurship ample scope exist to develop prescriptive theories addressing the governance of transformation based on the role of individuals. Relevant theoretical frameworks can be found in the literature on transformative leadership (Bass 1997), business entrepreneurship (Moon 1999), psychology (Conger, et al. 1987) and change management (Fiol, et al. 1999; Lewin 1951)

4 Conclusions

This report evaluates the potential and scope of a research program on 'Developing and Evaluating Infrastructure Transformation' under the theme of Governance of Transformation using 4 criteria:

1. Gaps in scientific knowledge and potential to achieve scientific breakthroughs
2. Science-policy interplay
3. Relevance of international policy problem
4. Suitability of the program to be implemented in the German scientific community

To address these criteria, we first indentified possible gaps in knowledge in the scientific literature using the Scopus data base and Google Search and a pertinent set of keyword. Science-policy interplay was addressed by identifying relevant stakeholders in the field and evaluate the potential contribution of a research program and the required time horizon based on their organization and activities. The Relevance of international policy problem was addressed using general information on the development of the policy issues over the last decades. Finally the suitability of the envisioned program to be implemented in the German and European scientific community was evaluated based on our analysis of the information on relevant scientific institutions related to the bodies of literature identified in the Scopus search. Furthermore we used the key-words of the

Scopus search to identify current and recent research programs to address this issue. Finally some theoretical frameworks with the potential to inspire and direct such a research program are loosely presented.

From our analysis it appears that a gap of scientific knowledge exists in the translation of governance of transformation to infrastructures and more specific water supply and sanitation in urban areas. A research program surmounting this gab in scientific knowledge is thus necessarily interdisciplinary and needs to build a bridge from the social to the natural and engineering sciences. Expected outcomes have the potential to open up an internationally visible and innovative research field. The availability of a limited number of pioneering publication in this field shows that such an endeavour is feasible. Especially when organized as a research program it seems feasible to surmount the progress made by individual pioneering researchers.

The fact that the policy problem is not emergent, has been identified decades ago and remained on the on the policy agenda, is, maybe somewhat counter intuitive, a strong argument for a research program with specifically focuses on governance approaches addressing transformation, transition and policy innovation. Lacking such approaches, the issue is most likely to remain persistent over the next decade and become ever more urgent.

From our Scopus analysis it appears that the 337 results up to the key-word infrastructure (appendix 1) mainly originate from American and European Universities with London School of Economics and ETH Zurich as relevant institutions. Relevant journals are European Planning Studies and Geographische Rundschau. These results indicate that a relevant research community on the governance of the transformation of infrastructures exist within Europe. The United Kingdom, Switzerland and The Netherlands are relevant partners while the position of German Universities is this field in not yet standing out. On the broader topic of governance of transformation, within Europe the universities of Manchester and Oxford are relevant partners.

Currently no research program specifically focusing on developing and evaluating urban water supply and sanitation infrastructure transformation does exist. Some research program share a focus on governance of transformation and water management. These programs however take a broader scope by addressing water in urban areas as an integrated issue (de Graaf, et al. 2009). These program come close to what is intended with this research topic and their integrated approach needs to be taken serious.

Interesting frameworks to inspire such a research program can be found in the socio-technical systems (Rip, et al. 1998) and socio-ecological systems literature (Ostrom 2009). The NEXT generation infrastructure research program (Arts, et al. 2008) and the literature on policy entrepreneurship (Mintrom 1997). For all these body of literature, the focus of this new research program should be on turning description into prescription.

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Annex 1 Results Scopus search

key words search														
level 1	**results**		**level 2**	**results**		**level 3**	**results**		**level 4**	**results**		**level 4**	**results**
governance	18390												
policy	162787		transformation	10012									
implementation	88866		transition	11451					water supply	12		Urban	1
management	317643	AND	structural change	4179	AND	infrastructure	337	AND	sanitation	2	AND	Rural	0
adaptive	63846		innovation	15881									
flexible	39739												
resilience	6373												
			transformation	2733									
evaluation	195365	AND	transition	2393	AND	infrastructure	119	AND	water supply	0	AND	Urban	0
			structural change	1008					sanitation	0		Rural	0
			innovation	1822									
			transformation	1									
institutional transplantation	42	AND	transition	2	AND	infrastructure	1	AND	water supply	0	AND	Urban	0
			structural change	0					sanitation	0		Rural	0
			innovation	1									

Annex 2 URL's relevant research programs

1. US Global Change Research Program http://www.globalchange.gov
2. Klimzug http://www.klimzug.de
3. Dutch Knowledge for Climate program (http://knowledgeforclimate.climateresearchnetherlands.nl)
4. KSI program http://www.ksinetwork.org/
5. Transitions and transition paths: the road to a sustainable energy system http://www.nwo.nl/NWOhome.nsf/pages/NWOP_5WCHJB),
6. Political ecology of infrastructures http://sustsci.aaas.org/content.html?contentid=2586) the International Human Dimension Program On Global Environmental Change http://www.ihdp-it.org/index.php?option=com_content&task=view&id=31&Itemid=56
7. Urban development and Transformation Processes in the Water Sector http://www.ihdp-it.org/index.php?option=com_content&task=view&id=38&Itemid=70
8. Next generation Infrastructures http://www.nextgenerationinfrastructures.eu
9. National Urban Water Governance Program http://www.urbanwatergovernance.com

Thematic Cluster:
„Governance of Transformation“

Application Area:
“**From Wastewater Treatment to Urban Metabolism**”

Report for preparing a call from the German Federal Minister of Education and Research (BMBF)

Submitted to:
Professor Dr. Claudia Pahl-Wostel, University of Osnabrück

Revised version

Leipzig, 30th April 2010

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Preface

The task of this brief report is to analyse the Application Area "From Wastewater Treatment to Urban Metabolism" within the Thematic Cluster "Governance of Transformation". The report will provide input (background material) for the German Federal Ministry of Education and Research (BMBF) for a call on water research.

The report is based on the following input/material:

- the Milestone Report "Future themes in water management in the context of global change"(Short list and full report), prepared for the Osnabrück workshop that took place 3rd -4th February 2010;
- the results of the Osnabrück workshop "Future themes in water management in the context of global change", from 3rd to 4th February 2010; minutes of the workshop (received via e-mail);
- the criteria for new project proposals that were also presented at the workshop.
- an analysis of the relevant literature in the Application Area (time horizon for literature review: 2000-2010);
- an internet analysis of important institutions conducting research in the Application Area. (UN Habitat, World Bank, etc.).

Content

1. Introduction: Urban water governance as a major application area for studying transformation processes

The rise of **urban areas** is one of the main challenges that societies are facing today. In 2007, for the first time in history more humans were living in cities than in the countryside. For many authors the 21st century will become the “urban age”, i.e. urbanisation will be regarded as *the* phenomenon of the new century. It is expected that the world’s urban population will increase by 3 to 6 billion over the next 50 years (Drangert, Cronin 2008). This trend does not only include increasing numbers of inhabitants, the increasing economic power of cities and urban agglomerations and increasing urbanisation rates, but also changes in resource flows within cities and between cities and their hinterland. It has to be stressed that it is not only the rise of megacities that marks this development. However, the developments in megacities can be seen as the tip of the iceberg, where transformation processes take place more rapidly and with a particular impact on human life and the environment.

Water management has always played a central role in urban development. At the beginning of urbanisation, cities were founded in places with favourable natural conditions. Next to the provision of agricultural products, the availability of and access to water was one of the decisive factors for selecting certain sites for founding cities. Many cities are located in the vicinity of water resources, along rivers or in coastal areas, with direct access to water with its diverse uses (water as a resource, e.g. as drinking water or for use in production; access to waterways; water as a medium to absorb city waste and wastewater).

While in the beginning of urban development the use of water in its diverse functions was unregulated, over time certain decisions were made about the allocation and the use of water. Cities decided upon the way in which water resources could and should be used (joint investments in water-related infrastructure, the access to water for its users, the regulation of water markets, the responsibilities, financing, building and organisation of wastewater infrastructure and so on. Thus, the decisions over water uses and water allocation were becoming an issue of **water governance**. This means that these decisions were not based solely on individual choices, but on joint (common; private and public) decisions with respect to water resource use, access to water and water allocation etc. In other words: (implicit or explicit) ‘property rights’, i.e. rights to use, manage or benefit from water, formed the basis for using and allocating the resource (see Box 1).

Box 1: 'Property rights' and water resources management

'Property rights' is a generic term covering a bundle of different rights over a resource (P). Not all of these are necessarily held by the same person. One can distinguish

- the Right to **Use**: A has a right to use P;
- the Right to **Manage**: A has a right to manage P and may decide how and by whom P shall be used;
- the Right to the **Income**: A has a right to the income from P, i.e. A may use and enjoy the fruits, rents, profits, etc. derived from P;
- The Right of **Exclusion**: others may use P if and only if A consents:
    - If A consents, it is prima facie not wrong for others to use P;
    - If A does not consent, it is prima facie wrong for others to use P.
- The Right to **Transfer**: A may temporarily or permanently transfer user rights to specific other persons by consent.
- The Right to **Compensation**: If B damages or uses P without A's consent, then A typically has a right to receive compensation from B.

Source: Birner 1999: 44; adapted from TEEB D1, Chapter 2

The most visible trend of water-related changes in cities in the past was the provision of **centralised infrastructure** in the cities of the developed world (Europe and the United States, but also in many other parts of the world such as Asia or Latin America). Huge water-provisioning services (pipelines; pumping stations) were built, enabling the far-reaching transportation of freshwater to city households and businesses. At the same time wastewater was centrally collected by canals and sewage systems with central treatment plants that served as end-of-pipe technologies. Today, in many European urban countries and in the U.S. more than 90 percent of urban wastewater is collected by central sewage systems and treated in wastewater treatment plants.

There have been numerous indications that these **centralised systems are neither suitable nor sustainable for future developments**, in particular with regard to countries outside of Europe and the U.S.:

- The increase in the population in many parts of the world is above an annual rate of 2 percent, with high differences between cities. A high share of this population growth is informal, i.e. migrants entering the cities from rural areas are not officially counted, and often settle in areas without sanitation and sewerage systems – these are very often the favelas at the urban fringe. It is very unlikely that the centralised urban infrastructure systems will grow at a similar rate in the future to cover the needs of the population.

- In other urban agglomerations the population is shrinking, e.g. in East Germany or in the former socialist countries of Central and Eastern Europe, but also in some other old industrial cities in Europe or the U.S. (e.g. Liverpool, Detroit etc.). This leads to problems in maintaining and financing the existing centralised water-related infrastructure. It is becoming more and more difficult to distribute the increasing share of fixed costs among existing water users.

- It is not only population growth but also climate change that is increasingly leading to water scarcity in many urban areas of the world. Hence, global change trends such as population developments, technological change, international trade, global climate change etc. overlap.

These urban transformation trends are leading to **new challenges in water management**:

Firstly, the existing infrastructure systems of the industrialised countries that are dominated by the paradigm of "centralised supply" are reaching their limits. They are at risk due to population change, technological change, climate change and ongoing transformation patterns. Instead, **new (decentralised) forms of provisioning water and wastewater treatment** will be required. This aspect, which is still oriented towards the water sector as such, amplifies the need for water re-use systems and other new technological systems for example in order to satisfy the needs of people living in urban areas.

Secondly and closely related to this, there are signs that the **perspective on wastewater treatment aspects is too narrow**. Instead, water resource systems have to be considered in a broader frame. In the case of wastewater treatment it is only the wastewater stream that is considered and optimised. Solutions have always been (and still are) only developed against the background of cleaning-up wastewater in order to protect inhabitants against diseases and improve hygiene. While this perspective on health and sanitation was justified in the 19th and 20th century, nowadays many of these sanitation aspects have been resolved (notwithstanding that new pathogens and pollutants are still causing major problems for the treatment of water) and the sustainable management of the resource 'water' becomes the focus. This broadens the perspective in several dimensions:

- from considering waste and wastewater streams to considering entire water flows – i.e. the various dimensions of water, including surface and groundwater resources, quality and quantity issues have to be included;

- from considering only specific sectors of the society and the economy (namely those that pollute and cause unhealthy water conditions) to *all* sectors that use and allocate water, including the entire demand side (private households, industry, agriculture, businesses) – thus water is a system and component which interacts with other systems;

- from considering blue water (i.e. water flows within the city and between the city and rural areas) to considering green water (i.e. the water use embedded in agricultural products);

- from considering technical aspects of water management to considering socio-economic aspects (e.g. the acceptance of water allocation and distribution rules; the definition of property rights; aspects of fairness and distribution) – technical systems alter the attitudes and behavioural patterns towards a resource; in addition, there is an interrelationship between water, and social and economic development.

These aspects that reach far beyond water treatment and that cover urban water flows in all its dimensions can be referred to as the **urban metabolism**. In the following we take a closer look at the urban metabolism and stress the impact of this concept on the need for and design of water-related governance structures.

2. Urban metabolism – analysis of current research

Urban metabolism analysis is a means of analysing and quantifying the overall fluxes of energy, water, material and wastes into and out of an urban region. Analysis of the urban metabolism can provide important information about energy efficiency, material cycling, waste management and infrastructures in urban systems (Sahely et al. 2003). Urban metabolism quantitatively measures a city’s impact on the natural environment (Warren-Rhodes, König (2001).

Metabolism as a **concept** emerged from ecological research and was only transferred to urban systems in recent decades. The origins stem from industrial ecology, history, environmental history and the history of technological change. The strong focus on history can be seen against the background that primarily change processes over a certain time period are analysed. While some of the studies cover centuries, e.g. from the beginning of industrialisation to the present (Barles 2007), other studies focus on a much smaller time horizon – decades of about 10 to 20 years (Zhang et al. 2008; Sahely et al. 2003; Warren-Rhodes, König 2001).

With respect to existing literature on urban metabolism, **four types of studies** focussing **on urban metabolism** can be distinguished (see Appendix)**:**

(1) Regional case studies. The focus of regional case studies is on a specific region, be it a city or a certain area. Available studies dealt with Puerto Rico, Shanghai, Berlin, Paris, the southern Appalachians, cities in the United States, Toronto, Hong Kong, and Tianjin (see case studies in the Appendix). While some studies take a more traditional perspective, analysing the impacts of water pollutants on the environment (Puerto Rico, Berlin, the Appalachians study), others are broader, taking the entire flows (resources, materials, emissions, water) into consideration (Paris, United States). While these studies prove to be valuable for understanding urban metabolism in every single case, they also exhibit that there is a lack of coherence and joint concepts.

(2) Ecological studies mainly deal with the ecological impacts of urbanisation. The focus is on ecological functions and services, e.g. the provision of clean water, protection from water-borne diseases, flood control, and the support of recreational ecosystem services. The studies have a narrow focus by analysing selected impacts of urban areas on biodiversity i.e. How do urban forests influence urban metabolism? What is the influence on stream ecosystem functions? What are the impacts on macro-invertebrate richness? What is the influence of urbanisation on groundwater recharge? (for details, see papers in Appendix). Only the UNESCO Urban Water Series also draws conclusions for urban planning and could serve as a useful example for more broadly addressing governance issues.

(3) Sustainability approaches. While the analysis of urban metabolism has been established as an appropriate approach for measuring flows, it also paves the way for assessing the sustainability of cities. With the sustainability concept, the normative aspect of how a city's functioning should be based on resource flows and how these flows should be changed come into play. Thus the concept of urban metabolism can be used as a guiding principle for designing more sustainable cities (Codoban, Kennedy 2008). Positive metabolism processes (i.e. those with decreasing resource flows) are distinguished from those that threaten the sustainability of cities (i.e. those that are characterised by increasing resource use) (Kennedy et al. 2007). The sustainability-oriented approaches of urban metabolism reveal a stronger focus on management aspects, e.g. control engineering (Beck 2005). This implies the inclusion of stakeholders in decision-making processes. Thus, it reveals a closer relationship with regard to governance transformation.

(4) Sociological approaches consider water as a means to exercise economic and societal power. Water has worked to either foster urban cohesion or generate new forms of political conflict. The sociological approaches focus on the way in which shareholders and stakeholders are included in or excluded from decision-making, oligopolistic supply structures, or the marketisation of goods such as water etc. (Gandy 2004). In general, these considerations point to societal developments that include the coercion of powers, while governance structures and the transformation of governance structures are not explicitly addressed.

Summing up the review of relevant literature, one can draw **four conclusions**:

1) A number of studies on urban metabolism do exist. However, they are small in number and cover only a few cities worldwide. Due to the fact that the concept is relatively new, there are rare examples of urban metabolism. Furthermore, from the review of these studies it becomes obvious that the concept of urban metabolism is rather diverse. Interpretation issues are prevalent due to a lack of common conventions.

2) In many cases it is not water that is addressed but the broader set of resource flows (including energy, food, materials, CO_2, etc.). When focussing on water it becomes obvious that the number of studies is even smaller.

3) Most studies aim at a better understanding of the environmental impacts of urbanisation processes. While this descriptive perspective has its merits, it is not clear whether and to what degree urban metabolism can be applied within decision-making tools and whether the concept can be fruitfully used to steer resource flows in urban agglomeration. In other words: there is a lack of action-oriented knowledge (“Handlungswissen”).

4) Closely related to the previous aspect: governance issues are rarely addressed in existing studies. The concept of urban metabolism is mainly applied by the natural sciences, while the social sciences dealing with governance issues do not – or only rarely – participate in this research.

These conclusions lead to recommendations for developing the application area as a research area.

3. Recommendations for Developing the Research Area

The proposed research area “From Wastewater Treatment to Urban Metabolism” should focus on the emerging concept of urban metabolism. It should address urban water issues in their entire breadth and depth. The project should transcend the traditional focus on centralised wastewater treatment. Instead, the ingoing and outgoing water flows between the city and rural areas should be analysed in order to develop sustainable (i.e. environmentally effective, cost-efficient, and socially acceptable) solutions for urban water management. This includes new and innovative forms of (decentralised) water technologies that are to be developed against the background of future needs.

It is recommended to set the focus of the water metabolism research area on two aspects:

- Firstly, research should contribute to the **evaluation and interpretation** of ingoing and outgoing water flows, i.e. not only the (positive) description but also the (normative) assessment of water flows should be addressed. This requires (a) the identification and development of suitable indicators as well as relevant criteria for assessing water metabolism. As the development of relevant criteria has to be based on inhabitants’ preferences, the inclusion of stakeholders in this process is imperative.

- Secondly, research should focus on **urban governance processes** in order to develop an understanding of the possibilities (and constraints) of steering and influencing urban metabolism. This requires the analysis of the relationship between governance structures and their impacts on resource flows. Typical research questions include: Does a centralisation of responsibilities lead to a centralised infrastructure system? What is the role of upper-governmental grants in selecting the type of infrastructure? Do neighbourhood-oriented solutions (closed water cycles, decentralised technologies, etc.) reduce resource flows? What is the role of participatory decision-making processes? What are the prerequisites for improving the water metabolism (in the sense that less water-related resources are consumed)?

The research area could consist of **one or several projects**. The projects should include relevant case studies and focus on (1) the development and interpretation of indicators and criteria, and (2) the understanding of the relationship between urban metabolism and urban governance. The research area could also consist of one over-arching “meta-project”, e.g., in the form of a “synthesis project”, and several “sub-projects” conducting case studies. As urban metabolism focuses on dynamic change processes within urban areas, the projects should include a certain time span in order to be able to explain changes in urban metabolism – in this respect they should be dynamic instead of static.

There should be **no regional (geographical) focus**. Research should be based on “good” case studies that can be conducted in “mature” urban regions of the developed world or in urban agglomerations of the developing world. However, applicants should carefully explain the choice and the relevance of the chosen case study.

The research should be **inter- and transdisciplinary** in nature. The interdisciplinary approach stems from the necessity to include natural scientists as well as social scientists in the research. The social scientists must not necessarily be historians but should include those disciplines in particular that are suitable to address governance issues. The transdiciplinary approach is required because the criteria for evaluating urban metabolism (e.g. with regard to sustainable development) have to be developed jointly with the inhabitants that are concerned.

4. Assessment of the Research Area against Criteria

Gaps in specific knowledge. The programme clearly addresses gaps in existing knowledge. As shown in section 2, there are only a few studies dealing with urban metabolism, and only very few dealing with water issues. These studies are very much case-driven and do not offer systematic answers for the urban water challenges of tomorrow. By addressing the urban metabolism perspective, a scientific breakthrough can be expected. A future-oriented research can be set up that not only addresses scientific challenges but also the societal challenge of sustainable urban water management. The research also paves the way for new and innovative interdisciplinary research at the interface of natural sciences and social sciences.

Science-policy interplay. By addressing the challenge of identifying adequate criteria and indicators the programme also seeks to implement a transdisciplinary research approach. The inclusion of stakeholders is imperative for two reasons: Firstly, the criteria for evaluating urban metabolism cannot be developed "exogenously", i.e. by researchers alone. Instead, they have to reflect the preferences and opinions of affected stakeholders – and thus have to be developed "endogenously". Secondly, the idea of developing foundations to "steer" urban metabolism requires the inclusion of those who have experience in steering urban processes and who are at the same time given the responsibility and capacity for steering. Here, the inclusion of stakeholders is required because their knowledge is essential for analysing governance processes, and the implementation of alternative governance structures cannot be achieved without their agreement (at least a majority of stakeholders should agree).

Relevance of the international policy issue. One can expect the perspective of urban water metabolism to gain increasing interest in the international policy arena. For many urban agglomerations the concept will deliver important criteria for managing urban water resources sustainably. Due to the impacts of global change (population growth, economic developments, climate change, etc.) on the urban water cycle, such concepts are urgently needed. There is no doubt that this topic will persist for some years to come.

Suitability of the research area for the German scientific community. The German scientific community is well prepared for conducting research in the area of urban metabolism. There is a great deal of experience in inter- and transdisciplinary programmes and projects. This experience is based on numerous EU and BMBF programmes, especially the BMBF programmes "GLOWA – Globaler Wandel des Wasserkreislaufs" and "IWRM – Integrated Water Resource Management". In addition, there is experience in megacity research, based on the three programmes of the German Research Council (DFG) "Informal Dynamics of Megacities", the BMBF megacity programme "Emerging Megacities", and the Helmholtz programme "Risk Habitat Megacity". Thus, the proposed research area can build upon achievements and experience from past projects. If the research area on urban metabolism is implemented, it can be expected that the collaboration between the natural sciences and the social sciences will even increase and further support the collaboration.

Literature

The literature quoted in the above text refers to the sources below (see Appendix).

5. Appendix

Appendix I: Literature Review on Urban Metabolism

(1) Regional Approaches

Urban streams in Puerto Rico: what can we learn from the tropics?
(ISI Web of Knowledge http://isiknowledge.com/)
Author(s): Ramirez A, De Jesus-Crespo R, Martino-Cardona DM, et al.
Source: JOURNAL OF THE NORTH AMERICAN BENTHOLOGICAL SOCIETY
Volume: 28 Issue: 4 Pages: 1070-1079 Published: DEC 2009

Abstract: Urbanization is increasing rapidly in tropical regions. Information on the response of tropical streams to urbanization is critically needed, but this information is limited. Here we summarize our current understanding of urban stream ecosystems in Puerto Rico, a tropical island with a high level of industrialization and large urban areas. We focused on 16 tributaries of the Rio Piedras watershed, which drains the San Juan metropolitan area, and 16 tributaries of the Turabo watershed, a rapidly developing suburban area. Urban effects on nutrients and aquatic macro invertebrates were similar to those described for other geographic regions. PO4, K, and Mg concentrations increased considerably with urbanization, PO4-P ranged from < 5 mu g/L in streams draining forested watersheds to > 500 mu g/L in heavily urbanized streams. Macroinvertebrate assemblage composition changed to dominance by tolerant taxa (e.g., snails, Chironomidae) as the proportion of urban land increased in the subwatershed. In contrast, other factors did not follow expected responses to urbanization. Stream hydrology was equally flashy in streams draining forested and urbanized watersheds. Urban streams were commonly channelized, but in contrast to studies done elsewhere, channel incision was not greater in urban than in forested streams. Degree of urbanization was not related to the integrity of the fish assemblages. River connectivity seems to be more important than urbanization in determining fish assemblage composition in Puerto Rican streams because all native species are migratory (i.e., diadromous). Urbanization increased water temperature and microbial activity. Overall, urban streams in Puerto Rico presented some unexpected responses to urbanization that seem to be the result of its island or coastal characteristics. Examples from Puerto Rico provide information on how tropical streams might respond to the impacts of urbanization.

Eco-health evaluation for the Shanghai metropolitan area during the recent industrial transformation (1990-2003)
(ISI Web of Knowledge http://isiknowledge.com/)
Author(s): Zhang H, Wang XR, Hob HH, et al.
Source: JOURNAL OF ENVIRONMENTAL MANAGEMENT Volume: 88 Issue: 4
Pages: 1047-1055 Published: SEP 2008

Shanghai is a cosmopolitan city and one of the most important economic centers in China, but is saddled with serious environmental problems resulting from a recent industrial transformation. This paper examines the interactive relationships between economic growth, eco-efficiency Of urban metabolism, and environmental performance of the Shanghai metropolitan area since the 1990S using 15 indicators. This Study has revealed an enhanced eco-efficiency of water and energy use as Well as all improved overall environmental quality)l in the central urban districts of Shanghai. Both TGDP (total GDP) and GDP per capita increased rapidly at the annual rate of 16.28% and 15.91 %, respectively. In contrast, energy consumed per 10 000 RMB YUAN GDP (ECG), water consumed per 10000 RMB YUAN GDP (WCG), wastewater discharged per 10000 RMB YUAN GDP (WWDG), and waste gases emitted per 10000 RMB YUAN GDP (WGEG) decreased at the annual rate of 9.34%, 10.69%, 14.57% and 8.52% respectively. The rapid decline in ECG, WCG, WWDG, and WGEG indicates,in enhanced eco-efficiency Of Urban metabolism. However, uncontrolled emission of wastes from domestic instead of industrial Sources adversely affected the overall environmental quality. Ill addition, Suburban areas have undergone rapid economic growth at the cost of human,111 health deterioration, as Measured by mortalities and

relative mortality ratios ofthree major diseases tumor, respiratory disease, and trauma/toxicosis). With Shanghai serving as the "locomotive" driving the economy of the Yangtze River Basin, effective pollution control policies and a network of regional coordination are urgently needed ill the globalization and ecological security of the entire area.

Identification and significance of sulphonamides (p-TSA, o-TSA, BSA) in an urban water cycle (Berlin, Germany)

(ISI Web of Knowledge http://isiknowledge.com/)

Author(s): Richter D, Massmann G, Dunnbier U

Source: WATER RESEARCH   Volume: 42   Issue: 6-7   Pages: 1369-1378   Published: MAR 2008

Abstract: Because of the nature of the water cycle in Berlin, a number of persistent wastewater residues are present in the surface water and may potentially reach the groundwater via bank filtration and artificial recharge. The occurrence and behaviour of the wastewater residues para-toluenesulphonamide (p-TSA), ortho-toluenesulphonamide (o-TSA) and benzenesulphonamide (BSA) through wastewater treatment, surface water, bank filtration and drinking water treatment was studied. In addition, groundwater below a former sewage farm was investigated. All three compounds are ubiquitous in the aquatic environment of Berlin. p-TSA concentrations are much higher than those of o-TSA and BSA. p-TSA was found in high concentrations in the wastewater influent (2 to 15 mu g/L), in the wastewater effluent (<0.15 to 2.34 mu g/L) and in sewage farm groundwater (<0.05 to 20 mu g/L) and in lower concentrations in the surface water (< 0.05 to 1.15 mu g/L), bank filtrate (<0.05 to 0.30 mu g/L) and drinking water (<0.05 to 0.54 mu g/L). p-TSA is considerably depleted during waste- and drinking water treatment (similar to 90% reduction each). The concentration ranges for o-TSA and BSA in wastewater influents were 0.11 to 8 mu g/L and <0.05 to 0.64 mu g/L, respectively, while the values for wastewater effluents were 0.14 to 4 mu g/L for o-TSA and 0.25 to 0.49 mu g/L for BSA. Wastewater treatment and drinking water treatment do not reduce the concentrations of o-TSA and BSA. The behaviour of o-TSA during wastewater treatment varies largely between different wastewater treatment plants where concentrations increase, remain constant or decrease. BSA forms during treatment. The concentrations measured in surface water, sewage farm groundwater, bank filtrate and drinking water were < 0.05 to 1.74 mu g/L for o-TSA and < 0.05 to 0.53 mu g/L for BSA.

Urban metabolism and river systems: an historical perspective - Paris and the Seine, 1790-1970

(ISI Web of Knowledge http://isiknowledge.com/)

Author(s): Barles S

Source: HYDROLOGY AND EARTH SYSTEM SCIENCES   Volume: 11   Issue: 6   Pages: 1757-1769   Published: 2007

Abstract: The aim of this paper is to analyse metabolic interaction between Paris and the Seine during the industrial era, 1790-1970, a period marked by strong population growth, technological changes, and the absence of specific legislation on environmental issues. The viewpoint focuses on exchanges of waters and wastes between city and river, quantifying them and tracing their evolution in the light of the strategies implemented by the stakeholders in charge. The study combines industrial ecology, local history and the history of technology.

From 1790 to 1850, waste matters, and especially excreta, were considered as raw materials, not refuse: they generated real profits. The removal of human excreta aimed not only at improving urban hygiene, but at producing the fertilizers needed in rural areas. Discharging them into the river was out of the question. But after the 1860s, several factors upset this exploitation, notably domestic water supply: night soil became more and more liquid, difficult to handle and to turn into fertilizer; once utilised, the water had to be removed from the house; at the same time, the sewerage system developed and had negative impacts on the river. Even so, Parisian engineers continued to process sewage using techniques that would not only ensure hygiene but also conciliate economic and agricultural interests: combined sewerage system and sewage farms. Both of these early periods are thus noteworthy for a relative limitation of the river's deterioration by urban wastes. Not until the 1920s, when domestic water supply had become the standard and

excreta came to be considered as worthless waste, was the principle of valorisation abandoned. This led to important and long-lasting pollution of the Seine (despite the construction of a treatment plant), aggravating the industrial pollution that had been in evidence since the 1840s.

Analysing the priorities that led to the adoption of one principle or another in matters of urban hygiene and techniques, with the causes and consequences of such changes, enables us to understand the complex relations between Paris and the Seine. From raw material to waste matter, from river to drain, the concept of quality in environment remains the underlying theme.

Variation in stream water quality in an urban headwater stream in the southern appalachians

(ISI Web of Knowledge http://isiknowledge.com/)

Author(s): Clinton BD, Vose JM

Source: WATER AIR AND SOIL POLLUTION Volume: 169 Issue: 1-4 Pages: 331-353 Published: JAN 2006

Abstract: We examined the influence of a forested landscape on the quality of water in a stream originating on an urban landscape and flowing through National Forest lands. Sample sites included an urban stream (URB), a site on the same stream but within a National Forest (FOR) and 2 km downstream from the URB site, and a small, undisturbed, forested reference tributary of the main stream (REF). We monitored stream water quality from March 2002 through June 2003. Average base flows for the three stream sites were URB = 184 L s(-1.) FOR = 420 L s(-1.), and REF = 17 L s(-1.) We analyzed weekly stream water samples for NO3- NH4+. PO4+. Cl-. K, Ca, Mg, SO4, SiO2, pH, conductivity, total suspended solids (TSS), and bacteria on a monthly basis. Most solutes were higher in concentration at the URB site, as were conductivity, TSS, and bacteria counts. Reductions in NO3-.NH4+. and PO4+. concentrations between the URB and FOR sites were inferred from changes in nutrient:chloride ratios. Bacteria populations were greater and more responsive to stream temperature at the URB site. Water quality responses to changes in stream discharge varied among sites but were greater at the URB site. By all measures, water quality was consistently higher at the FOR site than at the URB site.

Urban environmental history: what lessons are there to be learnt?

(ISI Web of Knowledge http://isiknowledge.com/)

Author(s): Schott D

Source: BOREAL ENVIRONMENT RESEARCH Volume: 9 Issue: 6 Pages: 519-528 Published: DEC 14 2004

Abstract: The paper traces the emergence of urban environmental history first in the United States and since the 1990s increasingly also in Europe. It identifies the development of large technical networks which provide cities with water and energy and which serve to take problematic Substances and waste out of urban areas as a central theme of this new subfield where scholars from urban history, environmental history and history of technology converge. The concepts of 'path dependence' and 'urban metabolism' are introduced as useful heuristic devices to assess long-term effects of these infrastructures in a holistic manner. The paper shows that the implementation of networks and related household technologies was accompanied by comprehensive processes of social and cultural adaptation which fundamentally altered the attitudes and behavioural patterns towards resource use. Lessons of urban environmental history are seen in providing long-term horizons to current debates over urban technologies and their environmental consequences.

Estimating the urban metabolism of Canadian cities: Greater Toronto Area case study

(ISI Web of Knowledge http://isiknowledge.com/)

Author(s): Sahely HR, Dudding S, Kennedy CA

Source: CANADIAN JOURNAL OF CIVIL ENGINEERING Volume: 30 Issue: 2 Pages: 468-483 Published: APR 2003

Abstract: An urban metabolism analysis is a means of quantifying the overall fluxes of energy, water, material, and wastes into and out of an urban region. Analysis of urban metabolism can provide important information about energy efficiency, material cycling, waste management, and infrastructure in urban systems. This paper presents the first urban metabolism of a Canadian urban region, and possibly the first for a North American city. It also makes a first attempt at comparing the urban metabolisms of a few cities worldwide. The most noticeable feature of the Greater Toronto Area metabolism is that inputs have generally increased at higher rates than outputs over the study years (1987 and 1999). The inputs of water and electricity have increased marginally less than the rate of population growth (25.6%), and estimated inputs for food and gasoline have increased by marginally greater percentages than the population. With the exception of CO2 emissions, the measured output parameters are growing slower than the population; residential solid wastes and wastewater loadings have actually decreased in absolute terms over the 12 year period from 1987 to 1999.

Escalating trends in the urban metabolism of Hong Kong: 1971-1997
(ISI Web of Knowledge http://isiknowledge.com/)
Author(s): Warren-Rhodes K, Koenig A
Source: AMBIO Volume: 30 Issue: 7 Pages: 429-438 Published: NOV 2001

Abstract: Urban metabolism measures quantitatively a city's load on the natural environment. We update the Newcombe et al. (3) pioneering study of Hong Kong's urban metabolism in 1971, highlighting trends in resource consumption and waste generation. Per capita food, water and materials consumption have surged since the early 1970s by 20%, 40%, and 149%, respectively. Tremendous pollution has accompanied this growing affluence and materialism, and total air emissions, CO2 Outputs, municipal solid wastes, and sewage discharges have risen by 30%, 250%, 245%, and 153%. As a result, systemic overload of land, atmospheric and water systems has occurred. While some strategies to tackle deteriorating environmental quality have succeeded, greater and more far-reaching changes in consumer behavior and government policy are needed if Hong Kong is to achieve its stated goal of becoming "a truly sustainable city" in the 21(st) century.

Statistical modeling of daily urban water consumption in Hong Kong: Trend, changing patterns, and forecast
(ISI Web of Knowledge http://isiknowledge.com/)
Author(s): Wong JS, Zhang Q, Chen YD
Source: WATER RESOURCES RESEARCH Volume: 46 Article Number: W03506
Published: MAR 6 2010

Abstract: This study attempted to address statistical properties and forecast of daily urban water consumption in Hong Kong from 1990 to 2007. A statistical model was formulated to differentiate the effects of five factors on water use, i.e., trend, seasonality, climatic regression, calendar effect, and autoregression. The postulate of the statistical model is that total water use is made up of base, seasonal, and calendrical water use. Daily urban water consumption in Hong Kong from 1990 to 2001 was modeled and the developed statistical model explains 83% of the variance with six factors: trend (8%), seasonality (27%), climatic regression (2%), day-of-the-week effect (17%), holiday effect (17%), and autoregression (12%). The model was further validated using an independent data set from 2002 to 2007, yielding a R-2 of 76%. The results indicated good performance of the developed statistical model in depicting the temporal variations of the urban water use in Hong Kong, offering an improved insight into urban utilization of water resources and acting as the theoretical support for effective urban water resource management in Hong Kong under the changing environment.

Towards sustainable urban water resource management: A case study in Tianjin, China
(ISI Web of Knowledge http://isiknowledge.com/)
Author(s): Bai XM, Imura H
Source: SUSTAINABLE DEVELOPMENT Volume: 9 Issue: 1 Pages: 24-35
Published: FEB 2001

Abstract: Sustainable water resource management has become a critical issue for the development of cities that suffer scarce water resources. Tianjin City, located in China's Huaihe basin, one of the most polluted and water-scarce river basins in the country, is a typical example in which water is posing a major constraint to the development. This paper examines the current status of the use of water resources, and the current practices and policy measures taken for water resource management in Tianjin, with a view to drawing lessons through an evaluation of these measures. The study illustrates the role of cities and their complex interaction with their peripheries for the allocation of scarce water resources, and it suggests that a systems approach should be adopted in order to analyse and understand the complexity of the entire picture. Based on this review and evaluation of Tianjin's experience, the authors propose a framework for sustainable water resource management in cities, emphasizing the importance of taking full consideration of resource/environmental capacity and an integrated systems approach for problem solving.

(2) Ecological approaches

Plants in urban ecosystems: Essential role of urban forests in urban metabolism and succession toward sustainability

(ISI Web of Knowledge http://isiknowledge.com/)
Author(s): Manning WJ
Source: INTERNATIONAL JOURNAL OF SUSTAINABLE DEVELOPMENT AND WORLD ECOLOGY Volume: 15 Issue: 4 Pages: 362-370 Published: AUG 2008

Abstract: The urban forest has several positive effects on urban metabolism: reducing urban runoff, consequent sewer overloads and resulting water pollution; and reducing heat islands through shading and transpirational cooling by tree leaves, which also reduces energy required for cooling buildings. It is likely that urban trees can mitigate CO2 emissions from combustion, thus reducing overall emissions from power plants. This has been modelled, but has not been verified by actual measurements. Large computer models have been used to predict uptake of air pollutants by urban trees. There is, however, considerable uncertainty about the validity of the predictions from these models. Very few real uptake data are available. Urban trees emit small biogenic volatile hydrocarbons (BVOCs), with amounts varying by species. BVOCs can become part of the photochemical oxidant cycle, increasing ozone levels in cities. It is likely, but unverified, that the urban forest can improve the quality of life for city residents. There is much to be learned about the characteristics and ecophysiology of trees selected for large urban plantings. Additional research will help to elaborate more fully the role of urban forests in urban metabolism and succession toward sustainability.

Stream ecosystem function in urbanizing landscapes

(ISI Web of Knowledge http://isiknowledge.com/)
Author(s): Meyer JL, Paul MJ, Taulbee WK
Source: JOURNAL OF THE NORTH AMERICAN BENTHOLOGICAL SOCIETY Volume: 24 Issue: 3 Pages: 602-612 Published: SEP 2005

Abstract: Ecologists have described an urban stream syndrome with attributes such as elevated nutrients and contaminants, increased hydrologic flashiness, and altered biotic assemblages. Ecosystem function probably also varies with extent of urbanization, although there are few stream networks in which this prediction has been studied. We examined functional characteristics of 6 tributaries of the Chattahoochee River near Atlanta, Georgia, USA, whose catchments differed in degree of urbanization. We conducted short-term NH4- and PO4-addition experiments to measure nutrient uptake velocity, which is the rate at which a nutrient moves through the water column toward the benthos. Both NH4 and soluble reactive P uptake velocities decreased as indicators of urbanization (i.e., % of catchment covered by high-intensity urban development) increased. The amount of fine benthic organic matter (FBOM) also decreased with increasing urbanization, and uptake velocities were directly related to FBOM. Uptake velocities were not related to ecosystem metabolism (gross primary production [GPP], community respiration [CR], or net ecosystem production) as measured with diel oxygen curves. However, NH4 uptake velocity increased as total stream metabolism (GPP + CR) increased in these streams as well as in other North American streams, suggesting that biotic demand drives NH4 uptake velocities across a wide range of stream ecosystems. Measures of ecosystem function responded differently to urbanization: ecosystem metabolism was not correlated with indicators of urbanization, although breakdown rate of Acer barbatum leaves was positively correlated and nutrient uptake velocities were negatively correlated with indicators of urbanization. Elevated nutrient concentrations associated with urbanization are usually attributed to increased inputs from point and non-point sources; our results indicate that concentrations also may be elevated because of reduced rates of nutrient removal. Altered ecosystem function is another symptom of an urban stream syndrome.

Invertebrate biodiversity in agricultural and urban headwater streams: Implications for conservation and management

(ISI Web of Knowledge http://isiknowledge.com/)
Author(s): Moore AA, Palmer MA
Source: ECOLOGICAL APPLICATIONS Volume: 15 Issue: 4 Pages: 1169-1177
Published: AUG 2005

Abstract: The urbanization of agricultural lands is currently one of the dominant patterns of land use change in developed countries. In the United States and parts of Europe, this has led to the implementation of agricultural land preservation programs and riparian protection and replanting efforts along urban streams. The ecological benefits of such programs for the conservation of freshwater biodiversity have yet to be fully explored. We designed a study to investigate the patterns of stream macroinvertebrate community structure along a gradient of agriculture to urban development, and the patterns among urban streams that vary in the amount of intact riparian buffer. In 2001 and 2002, we sampled the 29 small headwater streams comprising the outlying tributaries of four watersheds just north of Washington, D.C., in Montgomery County, Maryland, USA. This region has had dramatic urban development over the last 50 years, yet significant efforts have been made to maintain riparian buffets and promote preservation of agricultural land.

Macroinvertebrate richness was strongly related to land use, with agricultural streams exhibiting the highest macroinvertebrate diversity. Taxa richness was related negatively and linearly (no statistical threshold) to the amount of impervious surface cover. For the urban streams, there was a strong positive relationship between invertebrate diversity and riparian forest cover. Urban streams with high amounts of intact riparian forest exhibited biodiversity levels more comparable to less urban areas despite high amounts of impervious cover in their catchments. The agricultural headwater streams in this study were not only more diverse than the urban headwaters, but their levels of macroinvertebrate diversity were high compared to other published estimates for agricultural streams. These higher richness values may be due to widespread use of "best management practices" (BMPs), including no-till farming and the implementation of woody and herbaceous riparian buffers, which may alleviate many acute stressors caused by cultivation. These findings suggest that, if managed properly, the preservation of agricultural land from development may help. conserve stream invertebrate biodiversity, and that maintenance of riparian forests even in highly urbanized watersheds may help alleviate ecological disturbances that might otherwise limit macroinvertebrate survival.

Estimating Land Use Impacts on Regional Scale Urban Water Balance and Groundwater Recharge

(ISI Web of Knowledge http://isiknowledge.com/)
Author(s):He, B; Wang, Y; Takase, K; et al.
Source: WATER RESOURCES MANAGEMENT Volume: 23 Issue: 9 Pages: 1863-1873 Published: JUL 2009

Abstract: Anthropogenic activities have exerted increasingly large-scale influences on terrestrial ecological systems from the past century, primarily through agriculture; however, the impact of such changes on the hydrologic cycle is poorly understood. As one of the important land use (LU) in the

coastal Dogo Plain of the Seto Inland Sea, Japan, paddy fields have been decreasing with the increase in urbanization in recent decades. As the main source of water in the Dogo Plain, groundwater plays an important role in providing people with fresh water and contributing to stream base flow. The purpose of this study is to analyze the water resource and evaluate the effect of LU change on groundwater table fluctuation in this coastal plain. Firstly, the observations of groundwater table and the investigation of water balance were carried out in this alluvial plain. Then, a distributed four-block three-layer water balance model was employed to analyze the groundwater table fluctuation with response to the change of paddy field area. Moreover, the role of paddy field in recharging groundwater in the basin has been clarified. Results show that groundwater table depends not only on rainfall and discharge from rivers, but also on irrigation water and topology of the study area. The net groundwater recharge was positive in irrigation periods whereas that in non-irrigation periods was nearly equal to zero or negative. The results of this study would be helpful to the urban development policy and land use planning decision.

Aquatic Habitats in Sustainable Urban Water Management
(UNESCO Urban Water Series:
http://publishing.unesco.org/results.aspx?collections=73&change=E)
Science, Policy and Practice
Edited by Iwona Wagner, Jiri Marsalek and Pascal Breil
Urban Water series - UNESCO-IHP
2008, 978-92-3-104062-7
UNESCO Publishing / Taylor & Francis

Aquatic habitats supply a wide range of vital ecosystem benefits to cities and their inhabitants. The unsustainable use of aquatic habitats, including inadequate urban water management, however, tends to alter and reduce their biodiversity and thereby diminish their ability to provide clean water, protect us from waterborne diseases and pollutants, keep urban areas safe from flooding, and support recreational ecosystem services and even the aesthetic enjoyment of our world.

Aquatic Habitats in Sustainable Urban Water Management – the result of collaboration between UNESCO's International Hydrological Programme and its Man and the Biosphere Programme – aims at improving our understanding of aquatic habitats, related ecosystem goods and services, and conservation and sustainable use – with a special focus on their integration into urban water management. The first part of this volume reviews basic concepts and challenges in urban aquatic habitats, as well as strategies for their management integration. The second part examines technical measures related to habitats management and rehabilitation, along with their incorporation into urban planning and their role in human health. The final part looks at current urban aquatic habitat issues and practical approaches to solving them through the lens of case studies from around the globe.

(3) Sustainability approaches

Metabolism of neighborhoods
(ISI Web of Knowledge http://isiknowledge.com/)
Author(s): Codoban N, Kennedy CA
Source: JOURNAL OF URBAN PLANNING AND DEVELOPMENT-ASCE Volume: 134 Issue: 1 Pages: 21-31 Published: MAR 2008

Abstract: Analysis of urban metabolism has been established as an appropriate approach for assessing the sustainability of cities. A desirable next step is to use the metabolism as a guide to designing more sustainable cities. This study provides an analysis of the metabolism of four representative Toronto neighborhoods. The annual energy consumption for buildings and transport is determined to be from 57 to 107 GJ/capita and from 0.5 to 9.2 GJ/capita, respectively. The annual consumption of food and water is found to be 1,100 and 92,300 kg/capita. The findings of the study have implications for the design of sustainable neighborhoods. This includes the

construction of energy-efficient buildings, development of public transit, and encouragement of residents to replace inefficient water fixtures. More advanced methods might consist of growing the urban forest using nutrients from wastewater, and converting solar energy to building operational energy.

The changing metabolism of cities

(ISI Web of Knowledge http://isiknowledge.com/)

Author(s): Kennedy C, Cuddihy J, Engel-Yan J

Source: JOURNAL OF INDUSTRIAL ECOLOGY   Volume: 11   Issue: 2   Pages: 43-59   Published: SPR 2007

Abstract: Data from urban metabolism studies from eight metropolitan regions across five continents, conducted in various years since 1965, are assembled in consistent units and compared. Together with studies of water, materials, energy, and nutrient flows from additional cities, the comparison provides insights into the changing metabolism of cities. Most cities studied exhibit increasing per capita metabolism with respect to water, wastewater, energy, and materials, although one city showed increasing efficiency for energy and water over the 1990s. Changes in solid waste streams and air pollutant emissions are mixed.

The review also identifies metabolic processes that threaten the sustainability of cities. These include altered ground water levels, exhaustion of local materials, accumulation of toxic materials, summer heat islands, and irregular accumulation of nutrients. Beyond concerns over the sheer magnitudes of resource flows into cities, an understanding of these accumulation or storage processes in the urban metabolism is critical. Growth, which is inherently part of metabolism, causes changes in water stored in urban aquifers, materials in the building stock, heat stored in the urban canopy layer, and potentially useful nutrients in urban waste dumps.

Practical reasons exist for understanding urban metabolism. The vitality of cities depends on spatial relationships with surrounding hinterlands and global resource webs. Increasing metabolism implies greater loss of farmland, forests, and species diversity; plus more traffic and more pollution. Urban policy makers should consider to what extent their nearest resources are close to exhaustion and, if necessary, appropriate strategies to slow exploitation. It is apparent from this review that metabolism data have been established for only a few cities worldwide, and interpretation issues exist due to lack of common conventions. Further urban metabolism studies are required.

Vulnerability of water quality in intensively developing urban watersheds

(ISI Web of Knowledge http://isiknowledge.com/)

Author(s): Beck MB

Source: ENVIRONMENTAL MODELLING & SOFTWARE   Volume: 20   Issue: 4   Pages: 381-400   Published: APR 2005

Abstract: As cities grow they first impose substantial stress on their surrounding water environment, but then, as comprehensive wastewater infrastructure is installed. much of that stress is removed. It becomes possible to talk of rehabilitated watersheds. in which the river network, with its re-invigorated ecological health, passes through the urban landscape of (now) potentially intense polluting activities. Surface water quality becomes vulnerable to the transient pollution events arising from all manner of accidents. faults. failures, and contaminated-runoff events associated with the city's metabolism. including unreliability in the performance of its wastewater infra structure. The paper examines the role of High-Performance Integrated Control (H-PIC)-a combination of real-time control (RTC) and Integrated Urban Water Management (IUWM)-as an approach essential to managing water quality in such intensively developing watersheds. Rather than promoting H-PIC as the logical stage of operations that will follow planning. design, and construction in the life cycle of an infrastructure, discussion is set in the context of the sustainability of cities. in particular, in association with a measure of sustainability expressed in terms of the frequency spectrum of disturbances to which the aquatic environment is subject. In this more strategic setting, it is argued that control engineering (for achieving H-PIC) should be seen as having relevance beyond merely its conventional interpretation of closed-loop unit-process; automation, e.g., in opening up analyses of the stability and ecological resilience of an entire urban water infrastructure. It is acknowledged that "integration", as in IUWM and H-PIC, is likely to be realized in practice. because of the need for it expressed in the highest political circles of the sustainability debate. Given this, the paper examines the implications of the ongoing shift-from the technocracy of the past century to the democracy of stakeholder participation in the present century-for the more widespread use of information and communication technologies in managing water quality in urban water environments.

Energy and material flow through the urban ecosystem

(ISI Web of Knowledge http://isiknowledge.com/)

Author(s): Decker EH, Elliott S, Smith FA, et al.

Source: ANNUAL REVIEW OF ENERGY AND THE ENVIRONMENT Volume: 25 Pages: 685-740 Published: 2000

Abstract: This paper reviews the available data and models on energy and material flows through the world's 25 largest cities. Throughput is categorized as stored, transformed, or passive for the major flow modes. The aggregate, fuel, food, water, and air cycles are all examined. Emphasis is placed on atmospheric pathways because the data are abundant. Relevant models of urban energy and material flows, demography, and atmospheric chemistry are discussed. Earth system-level loops from cities to neighboring ecosystems are identified. Megacities are somewhat independent of their immediate environment for food, fuel, and aggregate inputs, but all are constrained by their regional environment for supplying water and absorbing wastes. We elaborate on analogies with biological metabolism and ecosystem succession as useful conceptual frameworks for addressing urban ecological problems. We conclude that whereas data are numerous for some individual cities, cross-cutting compilations are lacking in biogeochemical analysis and modeling. Synthesis of the existing information will be a crucial first step. Cross-cutting field research and integrated, multidisciplinary simulations will be necessary.

Managing urban water supplies in developing countries - Climate change and water scarcity scenarios

(ISI Web of Knowledge http://isiknowledge.com/)

Author(s): Vairavamoorthy, K; Gorantiwar, SD; Pathirana, A

Source: PHYSICS AND CHEMISTRY OF THE EARTH Volume: 33 Issue: 5 Pages: 330-339 Published: 2008

Abstract: Urban areas of developing countries are facing increasing water scarcity and it is possible that this problem may be further aggravated due to rapid changes in the hydro-environment at different scales, like those of climate and land-cover. Due to water scarcity and limitations to the development of new water resources, it is prudent to shift from the traditional 'supply based management' to a 'demand management' paradigm. Demand management focuses on measures that make better and more efficient use of limited supplies, often at a level significantly below standard service levels. This paper particularly focuses on the intermittent water supplies in the cities of developing countries. Intermittent water supplies need to be adopted due to water scarcity and if not planned properly, results in inequities in water deliveries to consumers and poor levels of service. It is therefore important to recognise these realities when designing and operating such networks.

The standard tools available for design of water supply systems often assume a continuous, unlimited supply and the supplied water amount is limited only be the demand, making them unsuitable for designing intermittent supplies that are governed by severely limited water availability. This paper presents details of new guidelines developed for the design and control of intermittent water distribution systems in developing countries. These include a modified network analysis simulation coupled with an optimal design tool. The guidelines are driven by a modified set of design objectives to be met at least cost. These objectives are equity in supply and people driven levels of service (PDLS) expressed in terms of four design parameters namely, duration of the supply; timings of the supply; pressure at the outlet (or flow-rate at outlet); and others such as the type of connection required and the locations of connections (in particular for standpipes). All the four parameters are calculated using methods and techniques that recognise the relationship between outflow at a water connection and the pressure experienced at that connection. The paper presents a case study where it is demonstrated that the new guidelines can provide an equitable and acceptable level of service throughout the design horizon of the project. (C) 2008 Elsevier Ltd.

Use and abuse of the urban groundwater resource: Implications for a new management strategy
(ISI Web of Knowledge http://isiknowledge.com/)
Author(s): Drangert, JO; Cronin, AA
Source: HYDROGEOLOGY JOURNAL Volume: 12 Issue: 1 Pages: 94-102
Published: FEB 2004

Abstract: Various human activities threaten the groundwater quality and resource under urban areas, and yet residents increasingly depend on it for their livelihood. The anticipated expansion of the world's urban population from 3 to 6 billion in the coming 50 years does not only pose a large water management threat but also provides an opportunity to conserve groundwater in a better way than up to now. The authors argue for a new way to manage urban activities in order to conserve the precious groundwater resource. The focus is on the quality of the discharged water after use in households. Restrictions on what is added to water while using it, e.g. detergents, excreta, paint residues, oils, and pharmaceuticals, are important to simplify the treatment and reuse of used water. Avoiding mixing different wastewater flows has the same positive effect. If increased volumes of wastewater can be treated and reused, the demand on the groundwater resource is reduced, as also occurs with demand management measures. Reduced discharge of polluted water to the environment from households and utilities also conserves the quality of groundwater and reduces sophisticated treatment costs.

Urban Water Security: Managing Risks
(UNESCO Urban Water Series:
http://publishing.unesco.org/results.aspx?collections=73&change=E)
Edited by Blanca Jiménez and Joan Rose
Urban Water series - UNESCO-IHP
2009, 978-92-3-104063-4
UNESCO Publishing / Taylor & Francis

Understanding the impacts of urbanization on the urban water cycle and managing the associated health risks demand adequate strategies and measures. Health risks associated with urban water systems and services include the microbiological and chemical contamination of urban waters and outbreak of water-borne diseases, mainly due to poor water and sanitation in urban areas, and the discharge of inadequately treated, or untreated, industrial and domestic wastewater. Climate change only exacerbates these problems, as alternative scenarios need to be taken into consideration in urban water risk management.

Urban Water Security: Managing Risks – the result of a project by UNESCO’s International Hydrological Programme on the topic – addresses issues associated with urban water risks. The first section of the volume describes risks associated with urban water systems and services. The volume then discusses the concept of risk management for urban water systems and explores different approaches to managing and controlling urban water risks. A concluding section presents case studies on managing urban water risks.

Integrated Urban Water Management: Arid and Semi-Arid Regions
(UNESCO Urban Water Series:
http://publishing.unesco.org/results.aspx?collections=73&change=E)
Edited by Larry W. Mays
Urban Water series - UNESCO-IHP
2009, 978-92-3-104061-0
UNESCO Publishing / Taylor & Francis

Integrated Urban Water Management (IUWM) is a new approach to managing the entire urban water cycle in an integrated way, a key to achieving the sustainability of urban water resources and services. The IUWM incorporates: the systematic consideration of the various dimensions of water, including surface and groundwater resources, quality and quantity issues; the fact that water is a system and component which interacts with other systems; and the interrelationships between water and social and economic development.

Integrated Urban Water Management: Arid and Semi-Arid Regions – the outcome of UNESCO's International Hydrological Programme project on the topic – examines the integrated management of water resources in urban settings, focusing on issues specific to arid and semi-arid regions. The urban water management system is considered here as two integrated processes: water supply management and water excess management. The first six chapters provide an overview of the various aspects of IUWM in arid and semi-arid regions, with emphasis on water supply technologies, such as artificial recharge, water transfers, desalination, and rainwater harvesting. Water excess management is examined in the context of both stormwater management and floodplain management. Case studies from developed and developing countries are presented in order to emphasize the various needs and challenges of water management in urban environments in arid and semi-arid regions worldwide. These case studies include: Mexico City, Mexico; Tucson, Arizona; Awash River Basin, Ethiopia; China; and Cairo, Egypt.

Data Requirements for Integrated Urban Water Management
(UNESCO Urban Water Series:
http://publishing.unesco.org/results.aspx?collections=73&change=E)
Edited by Tim D. Fletcher and Ana Deletić
Urban Water series - UNESCO-IHP
2008, 978-92-3-104059-7
UNESCO Publishing / Taylor & Francis

Integrated urban water management relies on data allowing us to analyse, understand and predict the behaviour of the individual water cycle components and their interactions. The concomitant monitoring of the complex of urban water system elements makes it possible to grasp the entirety of relations among the various components of the urban water cycle and so develop a holistic approach to solving urban water problems.

Data Requirements for Integrated Urban Water Managements – issuing from UNESCO's International Hydrological Programme project on this topic – is geared towards improving integrated urban water management by providing guidance on the collection, validation, storage, assessment and utilization of the relevant data. The first part of this volume describes general principles for developing a monitoring programme in support of sustainable urban water management. The second part examines in detail the monitoring of individual water cycle components. Two case studies in the final part illustrating attempts to deliver an integrated monitoring system help demonstrate the fundamental principles of sustainable urban water management elaborated here.

Urban Water Cycle Processes and Interactions
(UNESCO Urban Water Series:
http://publishing.unesco.org/results.aspx?collections=73&change=E)
By J. Marsalek, B. Jiménez-Cisneros, M. Karamouz, P.-A. Malmquist, J. Goldenfum and B. Chocat.
Urban Water series - UNESCO-IHP
2008, 978-92-3-104060-3
UNESCO Publishing / Taylor & Francis

Effective management of urban water should be based on a scientific understanding of the impact of human activity on both the urban hydrological cycle – including its processes and interactions – and the environment itself. Such anthropogenic impacts, which vary broadly in time and space, need to be quantified with respect to local climate, urban development, cultural, environmental and religious practices, and other socio-economic factors.

Urban Water Cycle Processes and Interactions represents the fruit of a project by UNESCO's International Hydrological Programme on this topic. The volume begins by introducing the urban water cycle concept and the need for integrated or total management. It then explores in detail the manifold hydrological components of the cycle, the diverse elements of urban infrastructure and water services, and the various effects of urbanization on the environment – from the atmosphere and surface waters to wetlands, soils and groundwater, as well as biodiversity. A concluding series of recommendations for effective urban water management summarize the important findings set forth here.

(4) Sociological approach

Rethinking urban metabolism: water, space and the modern city
(University College London: http://www.geog.ucl.ac.uk/about-the-department/people/academics/matthew-gandy/contact-details)
Author: Matthew Gandy
Source: City: analysis of urban trends, culture, theory, policy, action, Volume 8, Number 3, December 2004 , pp. 363-379(17)
Publisher: Routledge, part of the Taylor & Francis Group

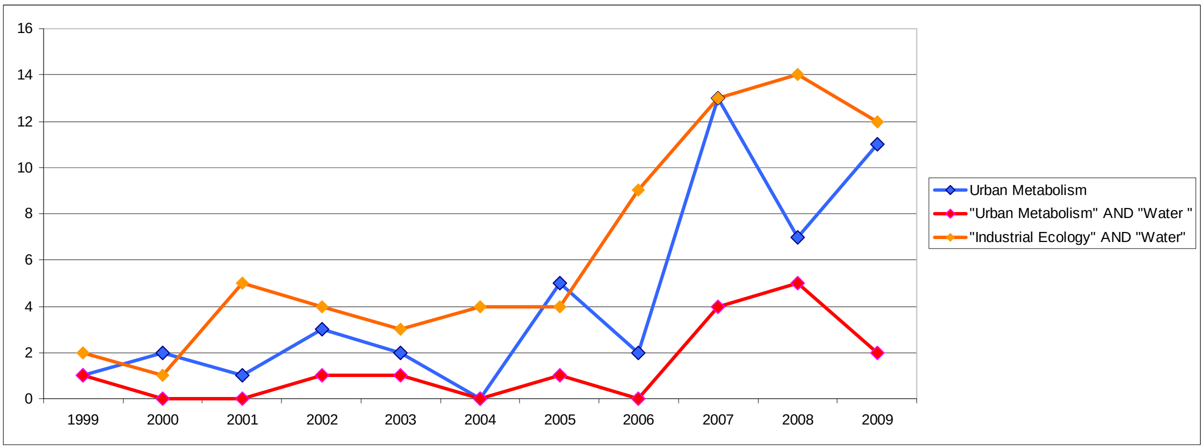
Abstract: 'Water is a brutal delineator of social power which has at various times worked to either foster greater urban cohesion or generate new forms of political conflict'. In the paper which follows, Matthew Gandy explores this statement by looking at the expansion of urban water systems since the chaos of the nineteenth-century industrial city. In this early period, the relationship between water and urban space can be understood by the emergence of what he calls the 'bacteriological city', defined by features such as new moral geographies and modes of social discipline based upon ideologies of cleanliness, a move away from laissez-faire policies towards a technocratic and rational model of municipal managerialism, and a connection between urban infrastructures and citizenship rights. Gandy goes on to discuss that while many cities never ultimately conformed to this model, the last thirty years has seen a fundamental move away from the bacteriological city to a more diffuse, fragmentary and polarized urban technological landscape. Characteristics here include declining investment in urban infrastructures, a desire to meet shareholder rather than wider public needs, oligopolistic structures amongst providers, the marketisation of goods such as water, increased health scares and mistrust from consumers, and polarisation of the quality of service provision. For Gandy, these shifts are better understood by more relational, hybridised, rather than functional-linear, notions of urban metabolic systems.

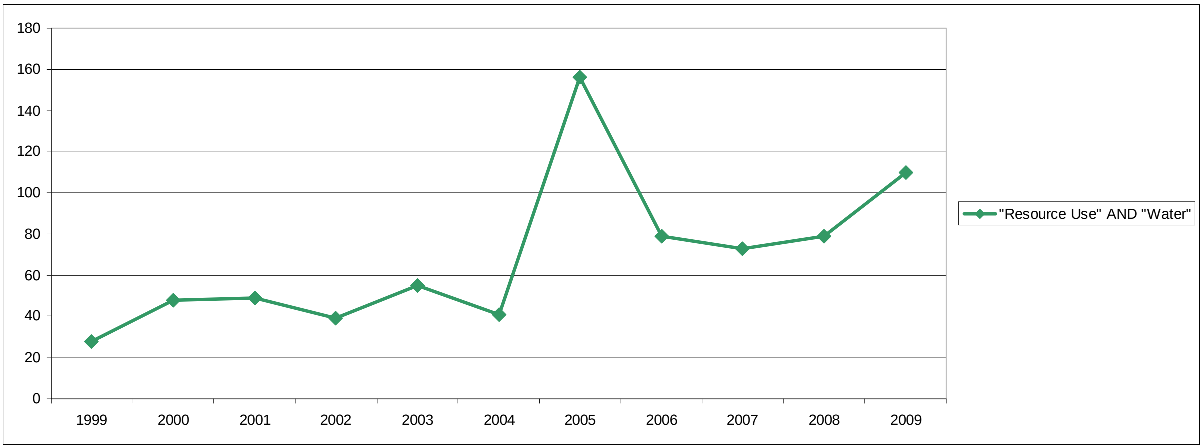
Full text: http://www.geog.ucl.ac.uk/about-the-department/people/academics/matthew-gandy/files/pdf2.pdf

Appendix II: SCOPUS Analysis

Quantitative Analysis – SCOPUS

Search Term	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Urban Metabolism	1	2	1	3	2	0	5	2	13	7	11
"Urban Metabolism" AND "Water "	1	0	0	1	1	0	1	0	4	5	2
"Resource Use" AND "Water"	28	48	49	39	55	41	156	79	73	79	110
Industrial Ecology	30	33	42	49	34	59	34	73	95	89	88
"Industrial Ecology" AND "Water"	2	1	5	4	3	4	4	9	13	14	12
"Urban Water"	x	x	x	x	x	x	x	x	x	x	x





Qualitative Analysis – some brief general observations

The current literature analysis covers the application areas "Urban Metabolism" and Water & Urban Metabolism", based on the "ISI Web of Knowledge" of Thomson Scientific Company and publications of international organisations, such as the UNESCO. The quantitative analysis is based on SCOPUS which was provided by the University of Osnabrück.

The focus of the analysis lies on the keywords "water" und "urban metabolism". In order to achieve completeness the two keywords were considered separately and in combination. In addition, similar topics, such as industrial ecology, were included.

The analysis reveals an increasing number of publications in the application area Water and urban metabolism. There seems to be an increasing scientific interest in this topic. The analysis was grouped in four major research approaches (see text above):

1. Regional Approaches – focussing on impacts of urbanisation in a distinct region;
2. ecological approaches- focussing on ecological impacts of urbanisation;
3. sustainability approaches – analysing the sustainable development of urban agglomerations; and
4. sociological approaches – analysing societal aspects of urbanisation processes.

For a detailed interpretation of the literature we refer to the above text.

Functional linkages of coupled natural and technical aquatic ecosystems: The outstanding role of interfaces in coupling natural and technical aquatic ecosystems

1. Introduction

Recent developments in environmental legislation in Europe, such as the EU Water Framework Directive require a more integrated approach to the management of hydrological catchments (Solimini et al. 2009). Similar approaches are advocated elsewhere (e.g. Winter et al. 2003). A holistic assessment and management of catchments requires a better understanding of interfaces between environmental compartments, especially in coupled natural-urban systems. There are numerous natural and technical interfaces in rural and urban water systems which link different compartments of the water cycle (e.g. surface water–groundwater, water–atmosphere, water–soils) or which link natural and technical urban water compartments (e.g. wastewater–gas in sewer systems and wastewater treatment plants, surface water–groundwater at bank filtration sites). Fluxes across interfaces are the exchange of water, dissolved substances, gases and energy between the different compartments. Interfaces are generally characterized by steep physical and biogeochemical gradients, disproportionately high numbers of micro-organisms, intense reactions rates and non-linear interactions as well as feedback mechanisms between the different systems. The interfaces themselves are heterogeneous (i. e. there are hot spots), process intensities fluctuate (i. e. hot moments occur) and interface structure might be dynamic if biota is involved or the system is disturbed by external impacts. All these circumstances make fluxes across interfaces highly complex and they are much less understood compared to processes in single compartments. Therefore, the state of the art in the field of fluxes across interface is characterized by considerable knowledge gaps.

Additionally, aquatic sediments act as dynamic sinks and sources in urban matter fluxes. Climate change, technical systems and management measures can change the function of interfaces in aquatic systems. Anaerobic processes in sediments should be investigated with focus on production of greenhouse gases and the remobilization of nutrients and harmful substances. Water quality might be altered when water transits highly reactive interfaces. For example, soil surfaces are an important interface linking atmosphere and hydrosphere. However, urban soils are drastically disturbed. Management of urban lawns and recreational lands are energy-intensive with a large input of fertilizers, pesticides and irrigation water. The free water surface is another interface linking atmosphere and hydrosphere. It acts as – partially bi-directional – exchange area of water (vapour), energy, (dissolved) gases (air, greenhouse gases) or nano-particles. The expected temperature increase due to anthropogenic climate change will affect the fluxes across interfaces via water surfaces thus influencing the urban micro-climate as well as lake dynamics, for example, due to shifts in ice cover periods. There is a strong need to study these fluxes, the effects on the linked natural-urban water cycle and the processes which control the fluxes.

All these interfaces were previously boundaries of environmental management units, but are now recognised to be important areas for cycling of energy, nutrients and organic compounds (McClain et al. 2003), and exert significant control over catchment-wide pollutant transfer

(Smith et al. 2009) and ecological health (Brunke and Gonser 1997). Four examples for coupled natural and technical ecosystems are given below:

- Bank filtration and artificial groundwater recharge systems: natural systems with some human impact are the river or lake and the adjacent aquifer. The infiltration of surface water into the aquifer is already part of the technical system of groundwater abstraction for the production of drinking water. The attenuation of unwanted surface water components during the passage of the aquifer is still part of the natural system. The space between lake and abstraction well is the interface of the natural and technical ecosystem with technical and natural processes active within the interface (Peters et al. 1998, Dillon 2002, KWB 2005).
- Self-purification of rivers: the technical ecosystem is the surface water body receiving high amounts of (treated) sewage. The natural ecosystem is the adjacent aquifer. In several cases streams in urban areas can be regarded as technical system since the content of treated sewage is high (sometimes even above 50 %) and the stream channel has been designed by water engineers. The hyporheic zone is the interface between both aquatic ecosystems. Natural processes such as biodegradation occur and reduce micropollutant concentrations. Water and reactants are delivered from the overlying technical and the underlying natural ecosystem and control turnover in the hyporheic zone (Petticrew et al. 2003, Gücker et al. 2006).
- Leaking sewer system: the sewer system is the technical system while the adjacent aquifer is the natural ecosystem. It is well-known that in most cities some proportions of sewer systems are quite old and leaking. Wastewater seeps into the aquifer. Along the cracks biofilms establish and result in some clogging of the cracks and some consumption of the load within the wastewater. The biofilm is the interface between the adjacent aquifer and the sewer system (Morgenroth & Wilderer 2000, Tchobanoglous et al. 2003, Wanner et al. 2006).
- City-lake system: On a larger scale a whole city can be regarded as technical system while the adjacent lake is regarded as natural system with some human impact. There are some impacts of the city onto the lake. As mentioned before, some sewage enters the aquifer. Furthermore, there are some contaminated sites due to former causes such as industry or accidents. Rainwater infiltration systems increase the amount of recharge. Summarizing, the aquifer coupling the city with the lake might be regarded as interface between the technical and the natural system (Walsh et al. 2003, Bjork 2004).

2. Application areas and their relevance

A better understanding of the interface processes in coupled natural and technical freshwater ecosystems is the key for making reliable predictions of natural and urban water cycles and aquatic ecosystems under changing boundary conditions (climate change, demography, emerging substances, and new technologies). Ecosystem management (e.g. river and lake restoration) is necessary to maintain or restore biodiversity at a landscape scale. To be effective, conservation efforts should be based on a solid conceptual foundation and a holistic understanding of river and lake ecosystems. Such background knowledge is necessary to re-establish environmental gradients, to reconnect interactive pathways, and to reconstitute natural dynamics responsible for high levels of biodiversity. The challenge for the future lies in protecting the ecological integrity and biodiversity of aquatic systems in the face of increasing pressures on our freshwater resources. This will require integrating sound scientific principles with management perspectives that recognize floodplains, groundwater and catchments as integral components of surface waters. Management should be based on sustaining, rather than suppressing, environmental heterogeneity (Ward 1998).

In that context, the following exiting research questions are to be addressed (e.g. Lovett et al. 2005):

- What are the physical and chemical boundary conditions that create ecosystem patterns and variations?
- What are the hydrologic processes that determine the variability in ecosystem structure and function?
- How do ecosystems interact with their aquatic and terrestrial environment?
- How does the water cycle interact with major biogeochemical cycles in ecosystems?

These topics which often have been investigated in a (more) isolated approach should be further developed in a strong interdisciplinary collaboration (water and environmental engineering, limnology, hydrogeology, chemistry, microbiology, environmental economy, social sciences and sustainability evaluations). Water issues need always a close connection and exchange between these fields of expertise (Royal Netherlands Academy of Arts and Science, 2005). Therefore, the following four application areas are identified to be representative for national and international research activities, including methodological issues. In the centre stands the land–water interface**,** connecting terrestrial and aquatic ecosystems, coupling natural and technical systems and the functional linkages of such interfaces.

2.1 Connectivity of water and landscapes

To date, most studies on land-water interactions have focussed on the one-way interaction from land to water by examining the transport of terrestrial derived materials to aquatic ecosystems (Walsh et al. 2003). Although there has been much research on the effect of land use on streams (Meybeck 1998), lakes (Gächter & Wehrli 1998), and wetlands (Lehtinen et al. 1999) there are still significant knowledge gaps. Furthermore, to fully understand the complex interactions between aquatic and terrestrial ecosystems, aquatic ecosystems must not only be seen as receptor of human modification of the landscape, but also as potential drivers of modifications of the landscape (Riera et al. 2001). It may be important to put more emphasis into developing stricter zoning around lake shorelines that limit development or find ways to increase the amount of lakeside vegetation. In seepage lakes the close coupling of lakes and groundwater is often overlooked. It is quite difficult to quantify the amount and distribution of groundwater and substances entering lakes. Innovative measurement concepts are required for the groundwater–lake interface which is sometimes equivalent to a natural–technical interface (compare section 1).

For streams, efforts have been put into place to preserve stream riparian and floodplain areas (see also Rockström et al. 2009). Riverine floodplains are highly complex, dynamic and diverse ecosystems, and they are ideal systems to study ecological impacts of multiple stressors at the local, regional and catchment scale (Tockner et al. 2007). Riverine floodplains are pulsed ecosystems with distinct flow, sediment, resource and thermal pulses and human modifications that truncate or amplify these pulses. That will have cascading effects on river-floodplain interactions by shifting the thresholds of connectivity, resilience or resistance - causing drastic regime shifts. Riverine floodplains integrate and accumulate multiple stressors at the catchment level, as reflected by distinct catchment fingerprints. The river-aquifer-interface may provide a very useful filter for controlling mass fluxes between groundwater and surface water systems. However, the interface is complex, it has spatially and temporally variable efficiency, it is prone to clogging but it is also able to regenerate (Tellam & Lerner (2009). If the processes occurring in this zone can be understood, it may be possible to harness its attenuation. It may even be possible in future to improve properties and ecological status of this interface by active engineering or management, such as by river restoration, catchment management, or ecological manipulations. However, there is much work necessary before these possibilities may be fully realized, perhaps in several decades time, from developing the understanding of the processes through improving measurement and monitoring technologies to advancing modelling techniques.

Hydrological processes involve flows of matter and energy between different landscape components. Such connections between e.g. hill slopes and channel networks are sometimes understood at the scale of experimental sites, but not at larger catchment scales where many ecological processes are evident and management decisions are needed (Soulsby et al. 2006, Tetzlaff et al. 2007).

To understand the interactions between catchment hydrology and ecology, the concept of connectivity has obvious potential as a unifying theme where exchange of concepts and ideas can occur. Understanding ecological processes in the context of explicit catchment hydrological processes offers an exiting research frontier in catchment hydrology, which has the potential to provide many important insights (Tetzlaff et al. 2007). Opperman et al. (2010) proposes a conceptual model that captures key attributes of ecologically functional floodplains, encompassing three basic elements: hydrologic connectivity between the river and the floodplain, a variable hydrograph that reflects seasonal precipitation patterns and retains a range of both high and low flow events, and sufficient spatial scale to encompass dynamic processes and for floodplain benefits to accrue to a meaningful level.

Resume: On the catchment or subcatchment scale there are still major research gaps. Most catchments comprise several closely coupled natural (e.g. rivers, lakes) and technical aquatic ecosystems (artificial channels, precipitation ponds, constructed wetlands…). A better understanding of the connectivity of (urban) landscapes and water bodies is required. Interfaces are the central compartment for the coupling of different aquatic systems as well as of aquatic terrestic systems.

2.2 Riparian zone processes

At a smaller scale, the riparian or hyporheic zone – the transition zone between surface water in rivers or streams and groundwater – is a connecting compartment between surface water and groundwater (Hyporheic Handbook 2009). It is a zone of intense biogeochemical activity and its ecological service is provided and sustained by the interaction of physical (e.g., transport of water and solutes), chemical (e.g., chemical reactions, sorption), and biotic processes (e.g., microbial transformation, bioturbation) by diverse and active communities

(Brunke & Gonser 1997, Sophocleous 2002). In recent years, the interest in an improved understanding of exchange processes has substantially increased (Jones & Mulholland 2000), and this interest is driven by the recognition of the riparian zone as a compartment of utmost importance for maintaining the ecological function of running waters. This ecological function is affected by anthropogenic pressure on surface waters, for example by an increased probability of droughts and floods as an effect of climate change (Brunner et al. 2009). Exchange of surface water and groundwater water with the riparian zone is closely linked to flow velocity, discharge, and water level in the river as well as to local and regional groundwater levels (Lewandowski et al. 2009). The fluctuation of groundwater levels in the vicinity of streams and rivers is strongly coupled to hydrologic events like floods and droughts (Humphries and Baldwin 2003). Riparian zones possess an unusually diverse array of species and environmental processes. The ecological diversity is related to variable flood regimes, geographically unique channel processes, climate shifts, and upland influences on the fluvial corridor. The resulting dynamic environment supports a variety of life-history strategies, biogeochemical cycles and rates, and organisms adapted to disturbance regimes over broad spatial and temporal scales. Innovations in riparian zone management have been effective in ameliorating many ecological issues related to land use and environmental quality (Naiman & Decamps 1997). Already in the earliest days of limnology, with regional limnology as the main field of research, it was quite clear that lake ecosystems also reflect the character of their catchment areas. The simple fact, that surface water and groundwater are carriers of solid and dissolved matter from catchment to lakes means that the shoreline should not be looked upon as a line of demarcation, but as a zone connecting terrestrial and aquatic ecosystems. A lake together with its catchment area constitutes, therefore, the primary ecological and management unit of a river basin. Water bodies are the mirrors in which the original state - and recent care, management and mismanagement - of the catchments are reflected (Bjork 2004).

<u>Resume:</u> A multitude of new or substantially improved experimental and theoretical approaches will have to be applied to analyze the interaction of physical, chemical, and biological processes in the riparian zone. For example, hyporheic exchange rates, residence times, and flow pathways of water and solutes have to be quantified; fluxes and turnover rates of organic micropollutants have to be measured at high spatial resolution using small sample volumes; the effect of heterogeneity and steep gradients on biogeochemistry and micropollutant processing have to be evaluated; the relevant constraints on biogeochemical processing in the hyporheic zone have to be identified; feedback mechanisms between hydrodynamic conditions and biogeochemical processing have to be established; models have to be developed bridging the substantially different processes and time-scales between running waters and aquifers across the hyporheic zone. The multifaceted nature of the hyporheic processes poses a challenge to developing successful restoration technologies, and necessitates continued research of an increasingly interdisciplinary nature (Hester & Gooseff 2010). It should be noted once again that in several cases the riparian zone is equivalent to the natural – technical interface (compare section 1).

2.3 Variability and heterogeneity at land – water interfaces

Heterogeneity of land surface (and subsurface) and atmospheric processes contributes to all aspects of the hydrological cycle. Understanding the types and sources of this heterogeneity is

a fundamental component of both theoretical and applied hydrology and ecology (Tague 2005). Analysis of heterogeneity in hydrology, as in other sciences, seeks to characterize and ultimately to explain spatial and temporal patterns in all of its forms and the pathways by which the water is transported and stored. This leads to the concepts of 'hydrologic landscapes' (Winter 2001), and 'flowpaths as integrators of heterogeneity in streams and landscapes' (Fisher & Welter 2005). During bank filtration infiltration capacity depends on water extraction and hydraulic resistance of the bed sediments. Lake bed hydraulics may be especially affected by clogging, which is dependent on settlement of fine particles, redox potential and other factors. In the field most of these processes are difficult to quantify and thus, when calculating responses to the pumping of the water flux across the sediment surface is assumed to be linearly dependent on the hydraulic gradient. However, this assumption was not adequate, and Wiese and Nützmann (2009) described the leakage coefficient as spatially distributed and also temporally variant. In natural systems, the chemistry of floodplain waters is a function of the source of the water, which is influenced by geologic and geomorphic features of riparian wetlands. However, anthropogenic disturbances may alter both geomorphic features and the natural balance of water mixing in the floodplain. Cabezas et al. (2009) studied riparian wetlands and characterized their water characteristics in one reach of the Middle Ebro River to assess the hydrochemical functioning of the system. Moreover, geomorphic characteristics of riparian wetlands were also analyzed to interpret the results at broader spatio-temporal scales. Total dissolved solids, major ions (sulfate, chloride, sodium, calcium, magnesium, and potassium) and nutrients (nitrate, ammonium and organic nitrogen, and phosphate) depended upon the relationships between surface and subsurface water flows. Seasonal changes and geomorphic characterization indicated that a strong functional dependence of floodplain wetlands close to the main river channel is established, whereas most of the floodplain area remains disconnected from river dynamics.
Rates and reactions of biogeochemical processes vary in space and time to produce both hot spots and hot moments of element cycling. Biogeochemical hot spots are defined as patches that show disproportionately high reaction rates relative to the surrounding matrix, whereas hot moments are defined as short periods of time that exhibit disproportionately high reaction rates relative to longer intervening time periods. As has been appreciated by ecologists for decades, hot spot and hot moment activity is often enhanced at terrestrial-aquatic interfaces. Hot moments occur when episodic hydrological flowpaths reactivate and/or mobilize accumulated reactants. By focusing on the delivery of specific missing reactants via hydrologic flowpaths, a better mechanistic understanding of the factors that create hot spots and hot moments is demanded by McClain et al. (2003). Such a mechanistic understanding is necessary so that biogeochemical hot spots can be identified at broader spatiotemporal scales and can be factored into quantitative models. The authors emphasize the needs for further research to assess the potential importance of hot spot and hot moment phenomena in the cycling of different bioactive elements, improve our ability to predict their occurrence, assess their importance in landscape biogeochemistry, and evaluate their utility as tools for resource management.
Lakes, far from being homogeneous environments which we might expect, offer a rich and dynamic heterogeneity at multiple spatial and temporal scales that we are just beginning to understand. Starting with the centimetre scale pore water concentrations in lake sediments vary horizontally as well as vertically several orders of magnitude within few centimetres (Lewandowski et al. 2002) due to hydrologic impacts of chironomids (Lewandowski et al. 2007). On a within-lake scale, a complex set of phenomena such as internal waves and stream

intrusions leads to both horizontal and vertical heterogeneity. Within a landscape, lakes often differ from each other both in their average characteristics and in their among-year dynamics. In landscapes dominated by groundwater flow, there is often more heterogeneity on lake characteristics and response to climatic events than in landscapes where exposed bedrock leads to rapid horizontal transport of water (Kratz et al. 2005).

Resume: Spatial heterogeneity and temporal variability in the landscape-water continuum have been central concerns in hydrology and ecology (Shaver 2005). Future priorities for research include dynamic approaches to heterogeneity in complex spatial networks, the search for broad patterns in heterogeneity across spatial scales, and reconciling the goal of environmental sustainability with the fact that we live in a patchy, constantly changing world. Causes and impacts of heterogeneity have to be studied in more detail. Especially for coupled natural and technical ecosystems heterogeneity occurring within interfaces is essential. Due to different water composition and increased reaction rates within hot spots processes might occur that are not possible assuming average concentrations (e. g. precipitation reactions might occur although on an average basis saturation indexes are not reached). Future advances in understanding of spatial heterogeneity and temporal variability will follow conceptual insights, theoretical developments, and methodological advances, as they always have.

2.4 Managing coupled natural and technical terrestrial - aquatic interfaces

The water balance of a landscape is a formative element of the natural ecosystem, in which man intervenes in a variety of ways, both direct and indirect (DFG 2003). On the one hand, river and lake restoration measures (e.g. aluminium addition to lakes, aeration of hypolimnetic water, river bank renaturation) are strongly connected to terrestrial-aquatic interfaces, and, on the other hand, the use of surface and/or subsurface water resources (e.g. for bank filtration and irrigation) is also related to these interfaces. Thus, the following examples are selected to give an impression of the variety of measures that influence hydrological and biogeochemical processes at aquatic-terrestrial interfaces to demonstrate the importance of an integrated water resources management.

To fully understand the impacts of human activity on the hyporheic zone, river managers need to work with scientists to conduct long-term studies over long river stretches or whole riverine landscapes. River rehabilitation and protection strategies need to prevent the degradation of linkages between the hyporheic zone and surrounding habitats while ensuring that it remains isolated from toxicants. Strategies that prevent anthropogenic restriction of exchanges may include the periodic release of environmental flows to flush silt and reoxygenate sediments, maintenance of riparian buffers, effective land use practices, and suitable groundwater and surface water extraction policies (Hancock 2002). River regulation, mining, agriculture, urban, and industrial activities all have the potential to impair interstitial bacteria and invertebrate biota and disrupt the hydrological connections between the hyporheic zone and stream, groundwater, riparian, and floodplain ecosystems. Until recently, the scientific ignorance of hyporheic processes has perhaps excused the inclusion of this ecotone in river management policy. However, this is no longer the case as we become increasingly aware of the central role that the hyporheic zone plays in the maintenance of water quality and as a habitat and refuge for fauna. Ultimately, riparian ecosystem function integrates climate (past and present), geologic materials and processes, soil development and attendant microbial transformations, subsurface characteristics, plant productivity, animal activities, and the active, continuous and variable feedbacks between the individual components (Naiman et al. 2005).

In technical wastewater purification systems biofilms as “degradation systems” are important. The ability of bacteria to attach to surfaces and to form biofilms can become an important competitive advantage over bacteria growing in suspension. A variety of microbial groups can contribute to the conversion of different organic and inorganic substrates. For example, when a wastewater contains a mixture of conventional and xenobiotic organic pollutants, biodegradation of the xenobiotics requires a population of slow-growing organisms capable of degrading the xenobiotics. Slow growers in suspension could be washed out of the system. However, in a biofilm, the slow-growing bacteria can establish themselves deeper inside the biofilm, protected from loss, while the conventional pollutants are removed near the biofilm-fluid interface (Wanner et al. 2006).

Regarding lake restoration, Gächter and Wehrli (1998) showed that irrespective of oxic conditions in the hypolimnion the sediment/water interface remained anoxic due to high sedimentation rates of organic matter unaffect by the restoration. This may explain why oxygenation did not increase the phosphorus (P) retention capacity of the sediment. Contrary to common assumptions, anoxic sediment surfaces and high P release rates may not be cause-effect related but simply two parallel symptoms of one common cause. Therefore, it is not surprising that fighting one symptom (anoxic hypolimnion and sediment surface) does not solve the other one (a high P release rate). The universal validity of the long-standing paradigm ‘oxygen controls the P release from sediments’ is doubted by Hupfer & Lewandowski (2008). The temporal existence of a thin oxidized sediment surface-layer could affect only fluctuations of the temporary P pool at the sediment surface but not the long-term P retention. The P retention of lake sediments strongly depends on sediment characteristics and land use of the catchment. The presence of redox-insensitive P-binding systems such as $Al(OH)_3$ and non-reducible Fe(III) minerals can enhance the P retention and completely prevent P release even in case of anoxic conditions. Alternative release mechanisms such as a dissolution of calcium-bound P and decomposition of organic P under both, aerobic and anaerobic conditions, are often more important than the redox driven Fe-coupled P cycle. Additionally, bacteria affect P cycling not only by altering the redox conditions but also by releasing P during mineralization of organic matter and by accumulation and release of bacterial P. Since microbial processes consume oxygen and liberate P it is difficult to distinguish whether oxygen depletion is the result or the cause of P release.

Besides P, the removal of nitrogen (N) in aquatic ecosystems is of great interest because excessive nitrate in groundwater and surface water is a growing problem. High nitrate loadings degrade water quality and are linked to eutrophication and harmful algal blooms, especially in coastal marine waters. Past research on nitrate removal processes has emphasized plant or microbial uptake (assimilation) or respiratory denitrification by bacteria. Burgin & Hamilton (2007) reviewed evidence for the importance of alternative nitrate removal pathways in aquatic ecosystems and discussed how the possible prevalence of these pathways may alter views of N cycling and its controls. These alternative pathways are of particular importance for the management of excess N in the environment, especially in cases where nitrate is transformed to ammonium, a biologically available and less mobile N form.

The influence of wastewater treatment (technical system) on aquatic ecosystems (natural system) has altered in the last decades. Secondary and tertiary wastewater treatment is common in developed countries, but little is known about the responses of lotic ecosystems to contemporary wastewater treatment plant (WWTP) discharge. Gücker et al (2006) examined the effects of WWTP discharge on various ecosystem components and functions of two morphologically and chemically impacted lowland streams near Berlin, Germany. Adverse effects of the WWTPs on the benthic invertebrate communities were small compared to effects reported in previous studies. This difference was a result of the higher purification efficiency of modern WWTPs, but also of significant structural degradation and eutrophication of the streams that already had impoverished the invertebrate community upstream of the WWTPs. Present-day WWTP discharges mainly cause eutrophication and subsequent side effects and low nutrient-retention efficiencies relative to the high nutrient concentrations and loads of impacted streams. The results highlight the need for efficient tertiary treatment of wastewater and for the refinement of agricultural practices to reduce diffuse nutrient loadings.

The construction of canals created new flowpaths that cut across historic stream channels, and the creation of artificial lakes produced sinks for fine sediments and hotspots for nitrogen processing. Further hydrologic manipulations, such as groundwater pumping, linked surface flows to the aquifer and replaced ephemeral washes with perennial waters. These alterations of hydrologic structure are typical by-products of urban growth in semiarid regions and create distinct spatial and temporal patterns of nitrogen availability. Constructed wetlands that mimic natural marshes have been used as low-cost alternatives to conventional secondary or tertiary wastewater treatment (Thullen et al. 2005). They showed that effective water treatment function and good wildlife quality within a surface-flow constructed wetland depend upon the health and sustainability of the vegetation, another 'interface' in the context described here. Although floodplains support high levels of biodiversity and some of the most productive ecosystems on Earth, they are also among the most converted and threatened ecosystems and therefore have recently become the focus of conservation and restoration programs across different countries and globally (Opperman et al. 2010). These efforts seek to conserve or restore complex, highly variable ecosystems and often must simultaneously address both land and water management. Thus, such efforts must overcome considerable scientific, technical, and socioeconomic challenges. In addition to proposing a scientific conceptual model, this paper also includes three case studies that illustrate methods for addressing these technical and socioeconomic challenges within projects that seek to promote ecologically functional floodplains through river-floodplain reconnection and/or restoration of key components of hydrological variability.

As listed in the introduction bank filtration and artificial groundwater recharge are typical examples for coupled natural and technical ecosystems (Ray et al. 2002, Peters et al. 1998). At a minimum, river or lake bank filtration acts as a pre-treatment step in drinking-water production and, in some instances, can serve as the final treatment just before disinfection. The main transformation (degradation) processes of diverse chemical compounds during this filtration occur at the surface water – groundwater interface sediments. Within the NASRI-project (KWB 2005) a comprehensive biogeochemical process understanding has been developed and, with the help of modelling tools – used for water quantity and quality calculation and interpretation – principal transferability is achieved. These comprehensively integrated results serve as a "model" for identifying missing bricks in the coupling of natural and technical aquatic systems.

Resume: The management of stressed river, lake and floodplain ecosystems is a major challenge for the near future and water managers worldwide. Management approaches need to be adaptive and embedded within a catchment-wide concept to cope with upcoming pressures originating from global change. Despite of the need for catchment-wide concepts extensive small-scale process studies are required to really understand the processes. Upscaling from small scales to whole catchment is another challenge. To build models that can cope reliably with different management scenarios a profound process understanding is the indispensible basis. To develop such a process understanding a combination of measurements (laboratory experiments, channel respectively mesocosm experiments, whole lake or river experiments and in situ studies) and modelling is necessary.

3. Summary

Towards a better understanding of terrestrial-aquatic interfaces in coupling natural and technical aquatic ecosystems four application areas are discussed to be of increasing interest for national and international research activities:

1. Connectivity of water and landscape
2. Riparian zone processes
3. Variability and heterogeneity of land-water interfaces, and
4. Managing coupled natural and technical terrestrial-aquatic interfaces.

The land-water interface may provide a very useful filter for controlling mass fluxes between groundwater and surface water systems. However, it is complex, having spatially and temporally variable efficiency, being prone to clogging but able to regenerate and also degenerate. If the processes occurring in this zone can be understood, it may be possible to harness its attenuation and in some instances flow-insulating capacity to very good effect. It may even be possible in future to improve these properties and ecological status of this interface by active engineering or management, such as by river restoration, catchment management, or ecological manipulations. However, there is much work necessary before these possibilities may be realized fully, perhaps in several decades time, from developing the understanding of the processes through improving measurement and monitoring technologies to advancing modelling techniques.

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Processed based understanding of hydrological-ecological linkages and feedbacks

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Relevance of application area

Background

Aquatic ecosystems are threatened by river regulation, diversion and over abstraction of water, pollution and spreading of exotic species. This does not only affect the aquatic ecosystems negatively, but also the ecosystem services these systems provide in terms of clean water, food production, pest and pollution control and so forth. Recognition of the escalating hydrological alteration of rivers and resultant environmental degradation has led to overarching policy frameworks, such as Integrated Water Resource Management (IWRM, Moriarty *et al*. 2004), to stress the importance of not compromising the sustainability of vital ecosystems when managing water resources. It is well recognised by scientists that the structure and function of a riverine ecosystem is determined by temporal variation in river flows (Poff *et al*. 1997).To protect freshwater biodiversity and the goods and services it provides, rivers needs to be managed in a way that mimic components of natural flow variability; magnitude, frequency, timing, duration, rate of change and predictability of flow events (Arthington *et al*. 2006).

The recognition of flow as a key driver of aquatic ecosystems has led to the development of the environmental flows concept. Environmental flows describes the quantity, quality and timing of water flows required to sustain freshwater ecosystems in managed rivers (Dyson *et al*. 2003). Other terms exist, such as minimum, or in stream flow. However such flows lack a holistic view of the ecosystem and the services it provides, focusing on only one or a few aspects. The need to provide for EF's is well recognized among freshwater scientists. In 2007, the Brisbane Declaration on Environmental Flows was endorsed by more than 800 delegates from 57 countries (Brisbane declaration, 2007). The declaration announce an official pledge to work together to protect and restore the world's rivers and lakes through incorporating EF's in water management strategies. The concept of environmental flows has shifted from incorporating only the aquatic ecosystems dependence on flow regime to a more anthropogenic focus incorporating the human dependence on ecosystem services. '*Environmental Flows describes the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems'* (Brisbane declaration, 2007). This can also be recognized in the scientific literature where there has been a steady increase in the number of papers incorporating the terms environmental flow and ecosystem services (fig1).

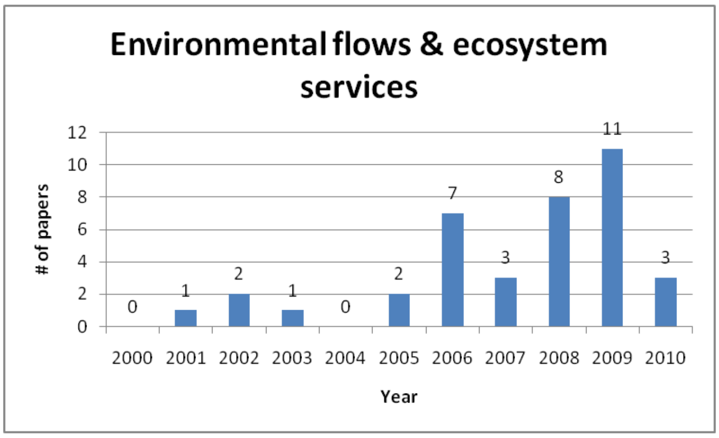


Figure 1. Web-of-Science literature analysis on search terms "environmental flow" and "ecosystem services". There were a total of 38 records that fitted the search criteria (see below), 34 articles and 4 reviews. The majority (37%) came from the US. 13% of the articles where published in Ecological Economics. (For further details see appendix 1)

Ultimately the ecological condition in which rivers and their services to humans are sustained is essentially a socio-political decision. Ecosystem condition may be determined by a negotiated and 'desired' EF by various stakeholders or a desired ecosystem condition may be set (e.g. by legislation), and the EF requirement is the water regime needed to sustain the ecosystems in that desired condition. Incorporating EF in water management allows for a more comprehensive, fair and sustainable utilisation of natural resources (Naiman et al 2002). Addressing environmental flows is indispensable to achieving the objectives of IWRM. However, the knowledge on how to do this in practice is still inadequate, leading to insufficient flow prescriptions in managed rivers. Despite numerous studies on effects of human alteration of flow, and the scientific consensus of the importance of a natural flow regime, translating general hydrologic-ecological principles and knowledge into specific management rules remains a daunting challenge (Poff & Zimmerman. 2010). One reason for this is that more specific quantitative data on hydrologic-ecological linkages and feedbacks are in short supply.

Ecosystem services

Ecosystem services can be categorized in four major groups: provisioning services, regulating services, cultural services and supporting services (Millennium Ecosystem Assessment 2005). Provisioning services are products obtained from ecosystems, including, for example, genetic resources, food and fiber, and fresh water. These are the most clearly recognizable of all of the types of services, because they provide direct products people can use, i.e. fish protein. Regulating services are the benefits obtained from the regulation of ecosystem processes, including, for example, the regulation of climate, water, and some human diseases. Supporting services are services that are necessary for the production of all other ecosystem services, like biomass production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling, and provisioning of habitat. Regulating and supporting services are more easily overlooked, but are equally vital, and their links and feedbacks to hydrological regime poorly understood.

Water for public supply, irrigation and industry is examples of a direct use of water, whilst water for ecosystems is water indirectly for people by supporting vital ecosystem services.

The services maintained by ecosystems have real economic values that are generally neglected in management cost-benefit analyses. These values are linked to the products provided by ecosystems (e.g. fisheries) as well as the avoidance of costs related to declining profits, remedial measures, damage repair, and health care. Healthy aquatic ecosystems are also to be valued for their adaptability and greater resilience in the face of pollution threats and climate change. There are trade-offs in terms of benefits received between allocating water to direct and in-direct human uses (fig 2). Addressing these trade-offs is necessary to maintaining the total long term benefits of aquatic systems.

Links and feedbacks between hydrologic regime and ecological processes

Poff & Zimmerman (2010) did a thorough review of ecological responses to altered flow regimes. They found that good quantitative data of flow ecology relationships where generally lacking across organism groups. Some groups such as fish were better represented than others. They found no studies that reported primarily on ecosystem functional responses to flow alteration (e.g. riparian production, nutrient retention and cycling, stream metabolism, etc.), even though many ecological processes are clearly flow-dependent (i.e. Hart & Finelli, 1999; Doyle et al., 2005). They conclude that this absence points to an obvious research gap when studying effects of flow alteration. A reason for this could be the often short-term, ‘snapshot’ nature of biological sampling done to document ecological change in flow-altered systems.

Riparian, floodplain and wetland productivity and hydrogeomorphology is linked to processes such as nitrogen retention and carbon storage and transport. The main driver behind these linkages is the flow regime (Tabacci et al. 1998). Given the importance of wetlands and aquatic ecosystems for the cycling of nutrients and carbon, it is important to understand how these linkages look like and how different water management options affect processes, to include the potential value when balancing trade-off in water use.

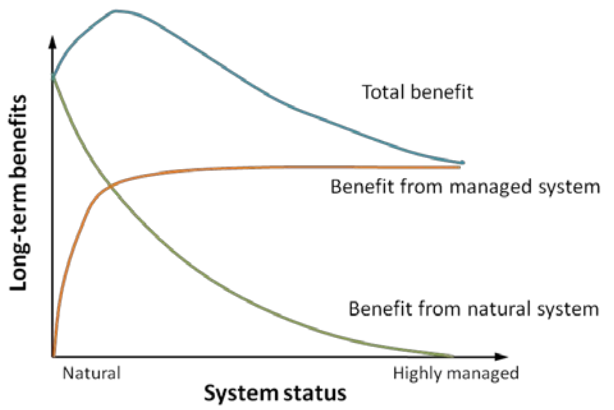
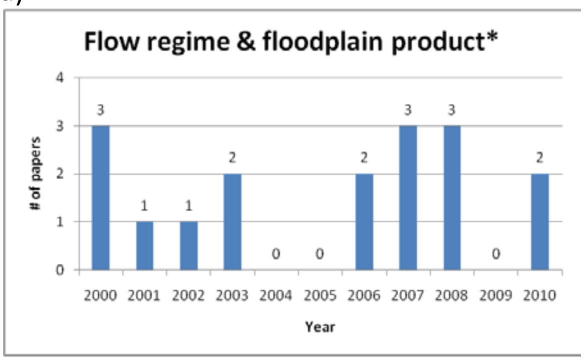


Figure 2. Modifications of natural systems continuously decrease the indirect benefits of the natural system (green line). At the same time, benefits from the highly managed system increase (orange line). Benefits from highly managed systems reach a plateau at some point, whilst the benefits of the natural system decline to zero at some point. The total long term benefits can be calculated by adding the benefits of the natural and highly managed systems. The total rises to a maximum before declining. It is at this point that the balance between naturalness and level of management is optimized (modified from Acreman 2001).

The links between hydrologic regime and riparian, floodplain and wetland productivity.

Riparian productivity is often lower in rivers where flow is regulated (Jansson et al. 2000). The main reason for this is hypothesised to be the lack of floods bringing nutrients to the riparian vegetation. For example flood frequency is important for the productivity and decomposition of plants. Padial & Thomas (1998) showed that floods, even of short duration, increase the decomposition rate and the nutrient cycling relative to dry conditions. Flow regime has an impact on growth response in riparian forests trees. Anderson et al. (2008) found a parabolic curve response to flooding, suggesting that there is an optimal flooding regime to promote growth. The relationship between riparian vegetation and flow regime may also differ between various functional groups (Robertson et al. 2001). A literature analysis revealed that the number of articles produced during the last decade addressing flow regime and productivity of riparian areas, flood plains and wetlands are quite few, just as Poff & Zimmermann (2010) claims (fig 3).

a)



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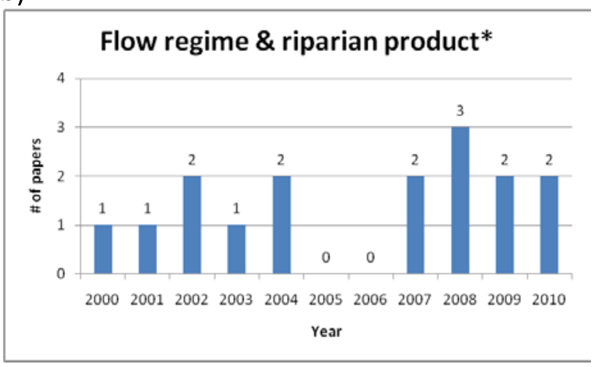

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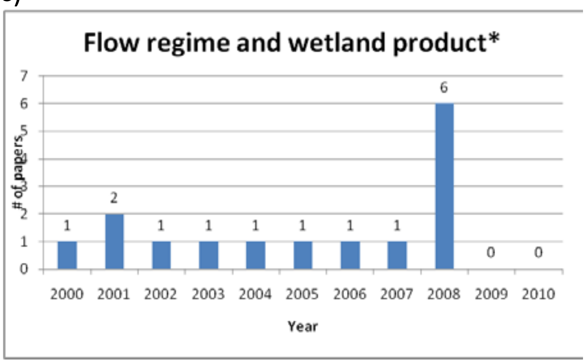


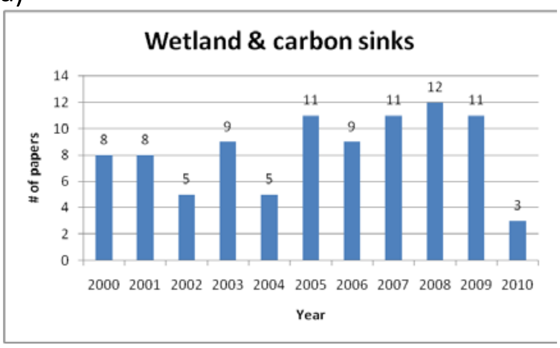
Figure 3. *Web-of-Science literature analysis on search terms a) "flow regime" and "floodplain product*", b) "flow regime" and "riparian product*" and c) flow regime and wetland product*".*

Hydro-ecological links in carbon cycling

The capacity of wetlands to store carbon is drawing increasing attention around the globe (Lenart 2009). Peat lands store 30% of the world's terrestrial soil carbon (Chivers *et al*. 2009). Leading experts and politicians alike argue that wetlands, in particular peat forming wetlands, should qualify as carbon credits in a global climate treaty, similar to that of forested land in the UN-REDD program. There was a push for this before the COP15 meeting in December 2009, but such a program was not adopted. A literature analysis showed a slightly increasing trend in papers that contained the search terms "wetland" and "carbon sink", and "wetland" and "carbon cycling" (many of the records in these two searches are likely the same, fig. 4).

However the role of wet lands in carbon sequestration is not clear-cut (Bridgham *et al*. 2006). Wetlands are also contributors of green house gasses to the atmosphere, primarily in the form of methane. Whether wetlands are carbon sinks or net contributors of green house gasses varies from site to site, but how this variation looks like is poorly known (Lenart 2009). Information on this across regional gradients would add to the understanding wetlands plays in the global carbon cycle. There is also a need for further knowledge on how flow management and water allocation affects carbon sequestration within a watershed. A study on water table and temperature manipulations in an Alaskan fen suggests that draught will decrease ecosystem carbon storage, while inundation will increase it by stimulating plant growth (Chivers *et al.* 2009). Methane and CO^2 dynamics is also influenced by soil property (Altor & Mitsch. 2008) and vegetation type (Miller & Fujii 2010). Increased knowledge on how hydrologic regime links with CO^2 sequestration and methane emission across larger spatial scales and between various types of wetlands would be valuable addition to incorporate in flow management schemes. A literature review focusing on the search terms "flow" and "carbon cycling", and "discharge" and "carbon cycling" showed an increasing trend in the number of papers being produced on the subject. A search more specified to "flow regime" and "carbon cycling" gave only 15 records over the last decade (fig. 5).

a)



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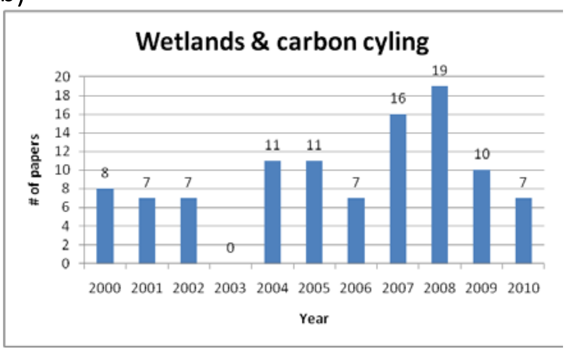


Figure 4. Web-of-Science literature analysis on search terms a) "wetlands" and "carbon sinks" There were a total of 123 records that fitted the search criteria (see below), 108 articles and 15 reviews. b) A search on the terms "wetlands" and "carbon cycling" gave a total of 143 records that fitted the search criteria (see below), 134 articles and 9 reviews. The majority of papers (64%) came from the US, Germany was the third largest contributor with 10% of the papers. (For further details see appendix 1)

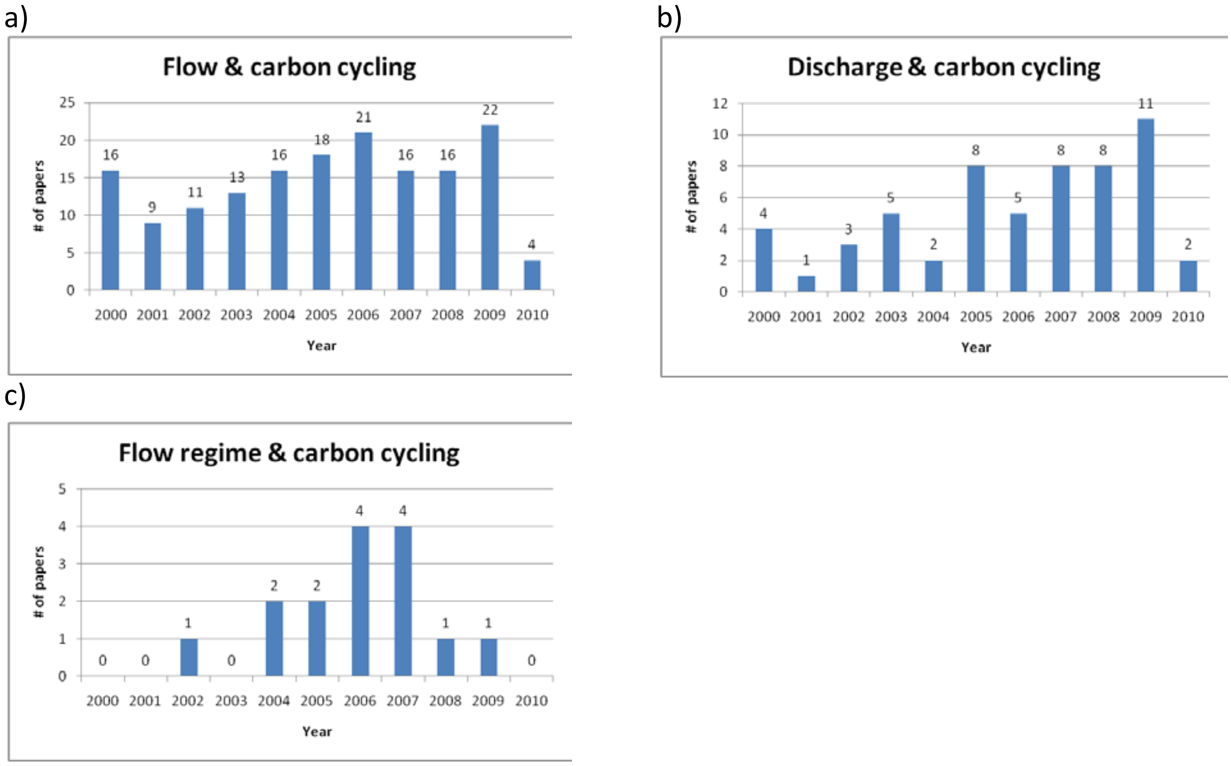


Figure 5. Web-of-Science literature analysis on search terms a) "flow" and "carbon cycling", b) "discharge" and "carbon cycling", and c) "flow regime" and "carbon cycling". There were relatively few articles matching the search criteria. There is however an increasing trend (for further details see appendix 1)

Hydro-ecological links in nitrogen cycling

Human activities have disrupted the natural biogeochemical cycling and doubled the rate of nitrogen input to terrestrial systems (Vitousek *et al*. 1997). This has in many cases led to greatly increased nitrogen loadings in rivers, estuaries and oceans. Floodplains are important sites for denitrification and nitrogen retention and it is well known that constructed wetlands in the drainage area and riparian buffer zones can reduce the amount of nitrogen run-of that reaches the stream and estuary ecosystems. In monetary terms, denitrification and nitrogen retention is calculated to have a great net worth. For the Danube, nitrogen processing was estimated to respond to half the wort of all ecosystem services combined (Gren *et al*. 1995). Wetland restoration and creation is increasingly being used as a mean to protect against harmful run-of, but restoration of flood plains is lagging behind. It is estimated that 90% of flood plain forests have been lost in Europe and North America (Tockner and Stanford 2002) due to flood protection measurements, damming and regulation of flow, and altering former floodplains to agricultural land.

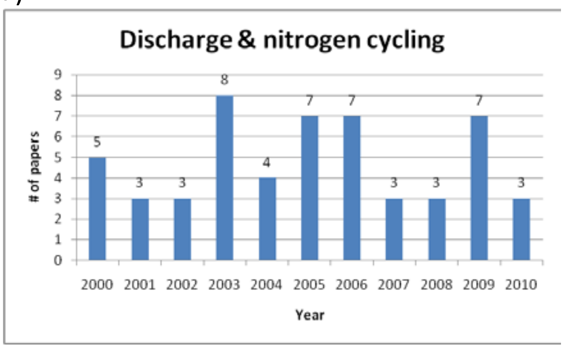
Fluctuating water levels creates aerobic and anaerobic conditions that are effective for enhancing denitrification (Reddy and Patrick, 1975; Groffman and Tiede, 1988). Nutrient cycling and export in streams and rivers should vary with flow regime, yet most studies of stream nutrient transformation do not include hydrologic variability (Hall et al. 2009). It is not well known how alteration to natural flow regimes affects floodplain denitrification

(Gergel *et al*. 2005), especially over larger scales. Kadlec (2010) found that nitrogen removal was enhanced in wetlands maintained by water pumping when introducing hydrological event (pulsed flow) compared to steady state wetlands. Hunter & Falkner (2001) found that more denitrification occurred in forested wetlands where the natural flow regime is maintained compared to restored wetlands where the hydrologic regime had not been established. Gergel *et al*. (2005) simulated the effects of flood alteration through upstream dams and setback levees on a generalized flood plain, mimicking features typical for Upper Mid-western US. They found that dams reduced nitrogen processing more than levees. Levees increased denitrification rates, but reduced overall denitrification through reduction in inundated area. A study on soil nitrogen cycling in riparian wetlands across a European climatic gradient found that water table elevation was the main driver on nitrogen cyling. Neither climatic factors nor vegetation type seemed to significantly affect denitrification rates (Hefting *et al.* 2004).

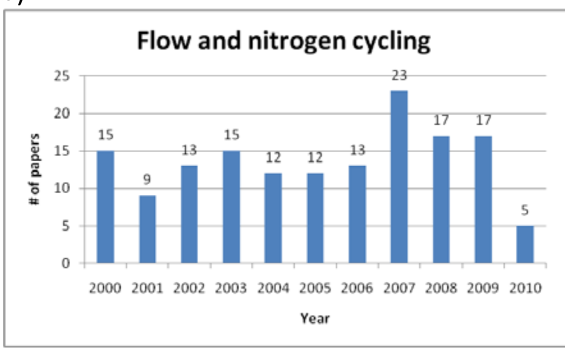
Pinay et al. 2002 raises some scientific challenges to improve our knowledge on the ecological consequences of changing water regimes on nitrogen cycling. These challenges mainly relate to; cumulative impacts of regime changes i.e. combination of changes in flow variables, scale of appraisal of these changes, and the relative impact of natural and human changes.

A literature analysis on search terms “discharge” and “nitrogen cycling”, “flow” and “nitrogen cycling”, and “flow regime” and “denitrification” gave relatively few articles matching the search criteria, especially when searching specifically on denitrification and flow regime (fig 6).

a)



b)



c)

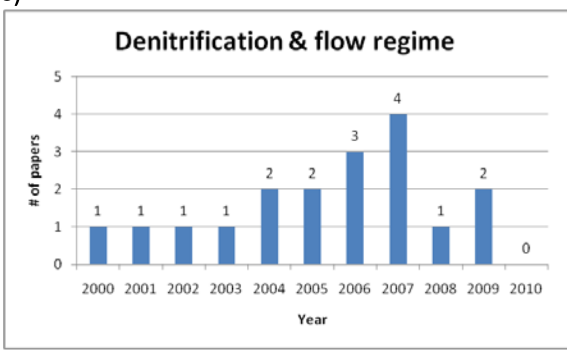


Figure 6. *Web-of-Science literature analysis on search terms a) “discharge” and “nitrogen cycling”, b) “flow” and “nitrogen cycling”, and c) “flow regime” and “denitrification”. There*

were relatively few articles matching the search criteria, especially when searching specifically on denitrification and flow regime (for further details see appendix 1).

Literature analysis

The literature analysis has been done in Web of Science. Search criteria for including records in the in the analysis were that the search terms would be included in title, abstract or key words, and that the records found would be categorized either as “article” or review. The analysis includes records between the years 2000-2010. Detailed results of each search are presented in Appendix 1. Selected abstracts from the various searches are included in Appendix 2.

Gaps in scientific knowledge and potentials to achieve scientific breakthroughs

Several gaps in scientific knowledge on understanding of hydrological-ecological linkages and feedbacks focusing on floodplain/wetland/riparian productivity, and carbon and nitrogen cycling have been identified. The most important is how these processes vary with flow regime, and how human alteration of flow affects these processes. Most studies found where site specific or focusing on only one type of system. A research program that focuses on larger spatial scales and across different types of hydrological landscapes, modeling flow-ecology response relationships would serve as valuable decision support system in water management. Results from such a program could also feed into a program focusing on functional linkages of coupled natural and technical aquatic ecosystems (i.e. rural-urban linkages). Preferably such a research program would run over several years in order to capture not only spatial, but also temporal variability in the driving variable; flow. However, also smaller projects would add valuable knowledge in obtaining a fuller understanding how flow alteration affects these ecosystem services.

Science –policy interplays

Assessing environmental flow needs is essential in obtaining a truly integrated water resource management. Many of the later methods for environmental flow assessment that have been developed include a social process where the goals are set on basis of a variety of affected stakeholders based on a deeper understanding of how flow alterations affects the aquatic ecosystems. In order to achieve an equitable and sustainable water resource management, which also reflects the goods and services provided by healthy ecosystems it is vital to understand potential trade-offs between different types of water uses. A research program focused on addressing hydrological-ecological linkages with an emphasis on linkages between hydrology, riparian/floodplain and wetland productivity and nitrogen and carbon cycling would give valuable contributions to a more informed water resource management. Results obtained in such a program would be helpful in developing regional environmental flow standards. It could feed into EU member countries work with implementing the EU water Framework Directive. It also has the potential to give valuable contributions to countries work with climate change mitigation efforts, and the role of wetlands and floodplain/riparian systems in the global carbon cycle.

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Theme cluster 9.1.4: Manipulating flow and water bodies for managing ecosystem services

Application area 3: Process-based understanding of social – ecological linkages and feedbacks

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Introduction

Ecosystems provide valuable services to humans. To distinguish between the various kinds of ecosystem services they can be categorized into provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment 2005). Humankind highly depends on these services, of which the provisioning services seem to provide the most obvious benefits as they are of a material nature, for example drinking water, fish and sea-food, as well as water for agricultural and industrial purposes. Albeit less visible the non-material services, such as climate regulation, pollination or nutrient cycling, are just as important for human well-being. Le Maitre et al. (2005) point out how ecologists have stressed human dependencies on ecosystem services for decades.

In recent history there has been growing recognition of the benefits humans derive from ecosystem services (e.g. Baron et al 2002, Daily and Matson 2008). By now the human dependency is a widely acknowledged fact and was reconfirmed by the Millennium Ecosystem Assessment Synthesis Report in 2005, which highlights the detrimental effects of ecosystem degradation on the services provided and, accordingly, on human society.

With increasing pressures on ecosystem services due to global change, specifically population growth and climate change, there is the risk of growing imbalances, which need to be addressed (e.g. Jackson et al 2001). In a recent IUCN publication it is advocated to make use of natural infrastructure since intact watersheds, floodplain and coastal areas can contribute to reducing people’s vulnerability and increase adaptive capacity through water storage, flood control and coastal defence. This forms the basis for reducing trade-offs and building resilience when combined with good governance and learning, whereas engineering solutions alone are not sufficient and can even have detrimental effects on resilience due to resulting environmental damage (see also Folke et al. 2004, Folke et al 2002).

Adaptive management and governance of resilience are thus needed to restore degraded ecosystems so that these are capable of delivering essential services even when changes occur (e.g. Folke et al. 2004, Adger et al (2005). Nelson et al (2007) suggest a systemic resilience framework to analyze adaptation processes and identify policy responses. With this framework they also go beyond the, so far, more common actor-centred approaches and link the social system to the ecological in order to identify the mechanisms of adaptation creating a learning environment. Consequently, a resilient social-ecological system may make use of crisis as an opportunity to transform into a more desired state (Folke et al 2005). The importance of addressing future challenges in an integrative manner is also highlighted by other studies, e.g. in a development context (Brown and Upmanu 2006), or with a special focus on the role of communities in ecosystem management (Fabricius et al 2007). Fabricius et al 2007 provide a synthesis of papers from a special issue titled “Strengthening People’s Adaptive Capacity for Ecosystem Management and Human Well-being”[1] categorizing different types of communities in relation to how they cope with change. Results show that

[1] www.ecologyandsociety.org/issues/view.php?sf=16

those communities able to improve their adaptive capacity can deal with challenges, trade-offs between short and long term effects on their well-being, and implement ecosystem management rules safeguarding ecosystem services.

According to Zehnder et al (2003) a fair distribution of freshwater between humans and nature is one of the major future challenges. It is evident that the social and ecological systems are closely intertwined and that a sound knowledge base and good understanding of the underlying processes and dynamics of social-ecological linkages are needed to arrive at sustainable ecosystem services management that equally caters for the human and environmental water needs.

2 Current state of research

2.1 Understanding of social – ecological linkages

The concept of ecosystem services aims at finding solutions to simultaneously conserve biodiversity and promote human well-being (Tallis et al 2009). According to Braimoh et al (2009) an underlying assumption of the Millennium Ecosystem Assessment (MA) is that due to the interconnectedness of environmental and human well-being, improvement of the former will lead to progress of the latter as well. However, this does not fully take into account the possible trade-offs. When improving one ecosystem service others may deteriorate as a result.

Furthermore, Tallis et al (2009) point out that only a few examples of successful win-win cases are known to date and that no guiding theories exist. According to Farber et al (2002) the chances of achieving win-win situation are likely to become even scarcer when looking t it from a fully global perspective. To gain a better understanding of what is currently being implemented in the field in order to integrate conservation and development goals they analyzed a total of 103 ecosystem service projects in over 30 countries. This explorative study purely documented and categorized what has been done within the scope of these projects in the context of developing countries and is only a first step in building up a knowledge base for better understanding specific social-ecological linkages. The actual outcomes of the implementation projects were not monitored by the researchers and only about a third of the projects monitor their own work.

Overall, despite their recognition many social-ecological linkages are not understood very well as they are very complex and information on the underlying dynamics and relationships are still lacking (e.g. Jewitt, 2002, Butler and Oluoch-Kosura 2006, Carpenter et al. 2009). This is also true for the ecological and social systems when looked at as separate entities. Various authors highlight that even though a lot of progress in research is being made the ecological understanding of ecosystem functions and services is still limited (e.g. Kremen and Ostfeld 2005, Daily and Matson 2008) (see also chapter on ‘Process-based understanding of hydrological-ecological linkages and feedback’). In a recent publication Bennet et al (2009) address this lack of understanding and develop a typology of relationships among ecosystem services in order to drive forward research in this field.

In relation to the social system Butler and Oluoch-Kosura (2006) point out that access to ecosystem services is not equally distributed. But even in cases of sufficient access and use of available services well-being is not automatically improved. Additional factors, such as income or the level of democracy, also play an important role in determining human well-being. Butler and Oluoch-Kosura (2006) further argue that the ‘causality between ecosystem services and well-being is bidirectional’, which means that the state of society also influences the state of ecosystem services.

2.2 Managing trade-offs between human and environmental water needs: the role of governance

Understanding the causal relations among different ecosystem services as well as between the ecological and social system is essential for being able to manage trade-offs.

Based on different studies dealing with trade-offs Braimoh et al (2009) provide an overview of the two main forms of trade-offs: spatial and temporal. Spatial trade-offs imply that through the use of one ecosystem service in a specific location another service is reduced or even lost in that same location or in the immediate surrounding. An example is the use of water for irrigation which limits the availability of water for other purposes. Spatial trade-offs also describe situations in which people in one area benefit from ecosystem services from a distant place, e.g. between rural and urban areas or between countries.

Temporal trade-offs often refer to intergenerational imbalances. Making use of ecosystem services to meet current needs may compromise the functioning of that and interlinked ecosystem services in future. Often the provisioning services are exploited in the short-term at the expense of long-term regulating or cultural services.

Falkenmark and Rockström (2004) stress that sustainable solution, which succeed in balancing the water needs of humans and nature, strongly depend on our ability to manage trade-offs and offer an ecological approach to find a balance. Daily (2000) promotes the so-called Ecosystem Services Framework to systematically characterize ecosystem services at the local, regional, and global level integrating biophysical and social dimensions. Overall, the problem of trade-offs is well recognized and associated assessment and management challenges are already being addressed. Modern holistic environmental flow assessment methods offer ways of evaluating trade-offs accounting for the fact that management choices play a vital role in determining the type and scope of spatial as well as temporal trade-offs (e.g. Rodríguez et al 2006). In this overall context participatory approaches play an increasingly important role. The current state of research on this is presented in the chapter on ‘Management tools for implementation of environmental flows’.

As was already pointed out in the interim report it is plausible to assume that water governance is a central determinant of trade-offs between ecosystem services (e.g. Braumann 2007, Pahl-Wostl 2009). Cumming et al (2006) found ecosystem services and governance are interlinked at various scales and that losses of ecosystem services are often caused by a mismatch of scales between ecosystem processes and governing institutions.

So far only little research is available that focuses on the linkages between water governance and ecosystem services, specifically analyzing the role of governance regimes and how these influence trade-offs at different levels and the state of the aquatic environment. Water governance is understood here quite broadly as defined by the UNDP: *“Water governance refers to the range of political, social, economic and administrative systems that are in place to regulate development and management of water resources and provisions of water services at different levels of society.”* (www.undp.org/water/about_us.html)

Brunckhorst (2002) emphasizes how resource governance can mediate between the needs of society, the economy, and ecosystem services to achieve sustainability and a continuation of ecosystem functions and services. The importance of good governance for managing freshwater ecosystems is also highlighted by Postel (2003). She looks at the trade-offs between natural and human water needs and calls for a change in the mindset as the water needs of ecosystems have been neglected so far, which is endangering the services freshwater ecosystems provide. Other studies linking governance and aquatic ecosystems tend to focus on marine ecosystems and fishery, which can be interpreted as a manifestation of their economic value. Ruckelshaus et al (2008), for instance, analyze marine ecosystem management and point out that governance structures play an important part in implementing ecosystem-based management. Further elaborations on the importance of governance are found in other articles on marine fishery. Hanna (1999) highlights how governance can contribute to sustainability in marine fishery and points out some functions that fishery governance must fulfill in order to achieve this goal. Juda & Hennesey (2001) focus on governance and the role it plays for the management concept of large marine ecosystems (LMEs) which was emerging at the time. They point out how ecosystem productivity, fishery, and ecosystem health have received most attention when analyzing LMEs whereas the socioeconomic dimension and governance have often been neglected in comparison. Accordingly they highlight the governance framework within which ecosystem-based management takes place and propose to develop governance profiles that present and analyze existing frameworks and call for further studies that look at governance and ecosystem use.

2.3 Valuation as a tool to safeguard ecosystem service functionality

Managing ecosystems services is closely associated with the valuation of these services, which is reflected in the Scopus literature: the search terms ‘ecosystem service’ and ‘water’ and ‘management’ generate a number of scientific articles addressing questions of valuation. Braumann et al (2007) highlight the intrinsic value of ecosystem services because humans benefit from their use independent of a monetization. However, as pointed out by Villa et al (2007) many of the studies focusing on valuation refer to monetized values which can then serve as incentives for conserving ecosystem services as in the case of Payments for Ecosystem Services (PAS) schemes (e.g. Jacka et al 2008).
Valuation is therefore an important supporting tool in decision-making especially with regard to water allocation. In this context Postel and Thompson (2005) draw attention to the fact that “*natural ecosystem services lie outside the traditional domain of commercial markets*” and are therefore “*undervalued and underprotected*”. Similarly Korsgaard et al (2008) address how environmental water needs are often disregarded and present an assessment approach which focuses on ecosystem services stressing the links between environmental flows and socio-economic values (see also chapter on ‘Management tools for implementation of environmental flows).

Altogether, there are many different approaches to valuation of ecosystem services and assessment frameworks. In a critical review Turner et al (2003) analyze these and find that: i) aquatic ecosystems received least attention, ii) the majority of studies was limited to single function valuation, and iii) only few monitored changes over time. The importance of valuating ecosystem service across temporal and spatial scales is also highlighted by Hein et al (2006). Additional perspectives on ecosystem service valuation are introduced by Kumar and Kumar (2008) who focus on the psycho-cultural dimension and Bhagwat (2009) who examines the spiritual significance of ecosystems and their services. Apart from that Meyerson et al (2005) draw attention to the fact that perceptions of the importance of ecosystem services to society can vary, which must be addressed appropriately by decision-makers.

The importance of valuation as a tool for managing ecosystem services and trade-offs seems to be widely agreed on and a multitude of approaches to valuation exist. Despite the clear advances of research on ecosystem service valuation Liu et al (2010) conclude that further syntheses of tools, skills and methodologies across the different disciplines are needed. As already pointed out in the interim report the future challenge is to combine existing approaches to find ways of operationalizing valuation consistently and reproducibly. Furthermore, Plummer (2009) draws attention to the fact that assigned values are site-specific and benefits are therefore difficult to transfer from one location to a similar one. One of the latest approaches to ecosystem valuation is the so-called ‘sequential decision support system’

(Turner et al 2010, Morse-Jones et al 2010) which takes these and other difficulties into consideration and is specifically aimed at practitioners.

3 Recommendations for future research

The literature review underlines the relevance of social-ecological linkages and human dependencies on aquatic ecosystem services. At the same time, it is evident that there are still significant research gaps, which need to be addressed in future research.

Gaps in scientific knowledge and potential to achieve breakthroughs:

For the interim report a number of research needs were already identified in relation to: quantitative knowledge about the status and importance of fresh water ecosystems including ground water, implementation difficulties of environmental flow assessments, valuation of ecosystem services, the role of governance regimes, as well as the adaptation capacity of social-ecological systems. During an international expert workshop on 'Future trends and research needs in water management' held in Osnabrück in February 2010 the original list served as a starting point for discussions and was further refined by a panel of experts. As a result recommendations for future research were made. According to the discussion outcomes the key challenges of future research related to process-based understanding of social-ecological linkages include:

- gaining sound understanding of social-ecological linkages as a basis for developing adaptive management strategies
- improving knowledge base for the valuation of ecosystem services to foster greater appreciation of ecosystem services in water management policy and to support decision makers
- improving knowledge base on the role of governance and how it can address human dependencies and balancing human and environmental water needs
- analysing the dependencies of social-ecological linkages and identifying best case scenarios
- analysing human water needs and balancing trade-offs between these and environmental water needs

Overall, the literature review confirms the experts' view on research gaps and offers further specifications. Keeping in mind the potentials for achieving scientific breakthroughs, the following points represent some of the main gaps to be addressed according to the literature review:

<u>Understanding social-ecological linkages & trade-offs</u>

- improve empirical database on the ecological system
- further analyze relevant social factors and their interrelations that play a role in supporting human well-being
- quantify environmental and human water needs
- analyze multiple cause and effect relations in both directions between the social and ecological systems across temporal and spatial scales
- develop methods to transfer results from one area to a similar one without neglecting the context-specific particularities

Improved understanding of the social-ecological linkages and the underlying dynamics and processes forms the fundamental basis for managing ecosystem services sustainably.

Ecosystem service management including valuation & the role of governance

- monitor and evaluate the implementation of ecosystem service projects and identify principles for best practice
- further analyze the role of governance and identify critical factors that provide a framework for adaptive capacity of social-ecological systems
- evaluate existing policies and practices and their underlying assumptions
- mainstream and operationalize valuation approaches

At a more general level, scientists argue for developing a common conceptual basis to advance research (e.g. Cramer et al 2008). There is an increasing interest in this area of research and many different approaches to managing ecosystem services have been suggested, often without referring to already existing methods.

In addition to this future research will also need to address the question of how to deal with uncertainties. Even though the knowledge base can still be improved greatly with further research, science will not be able to provide answers to all the questions related to future developments. First studies that work with quantitative and qualitative scenarios to address uncertainties are already available (e.g. Alcamo et al 2005, Bohensky et al 2006, Carpenter et al 2006, Nelson et al 2006). Further research in this field is needed and Nicholson et al (2009) conclude that "[…], *if we explicitly acknowledge and address uncertainties and complexities in the provision of ecosystem services, progress may appear slower but our models will be substantially more robust and informative about the effects of environmental change*", and can therefore provide assistance to decision-makers.

The interest in research on ecosystem services, governance, or explicitly water governance is growing (see table 1) but they appear to be treated as separate entities. Some studies on governance in general do mention that the functional processes of ecosystems depend on how resources are governed (e.g. Brunckhorst 2002) but all in all scientific publications explicitly dealing with water governance and aquatic ecosystems services are rare. This is clearly shown in table 1 presenting results of a bibliometric analysis of publications using the SCOPUS data base[2]. Different combinations of key words were used to define "search terms". The search results include the number of publications in peer reviewed journals in the search space "articles and reviews" that included the "search term" in the abstract, title or key words.

Table 1: Results of a bibliometric analysis of publications using the SCOPUS data

Search Term	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
"Ecosystem Service"	32	36	45	64	77	76	122	213	280	379
"Ecosystem Service" AND Water	9	15	15	22	22	26	43	60	90	107
Governance AND Water	12	18	36	19	39	59	58	86	106	135
"Ecosystem Service" AND Water AND Governance	1	1	0	0	0	0	1	1	1	0

So far ecosystems services have mostly been a subject of research in the natural science (Kremen and Ostfeld 2005), which is also reflected in the Scopus analyses. Social science

[2] Only parts of the SCOPUS results are presented in this report. The full results with tables and figures are included as a file on the CD accompanying this report.

approaches are clearly underrepresented. To address this research gap many authors agree that interdisciplinary rather than disciplinary approaches are needed (e.g. Carpenter et al 2009).

3.2 Science policy interplay

At the international level the significance of ecosystem services has already been recognized and is reflected in the establishment of the UNEP ad hoc intergovernmental and multi-stakeholder group which addresses the intergovernmental science-policy interface on biodiversity and ecosystem services. The group has already met twice in 2008 and 2009 - the last meeting will take place in June 2010 - and agreed on the aims to find ways of improving the science-policy interface for biodiversity and ecosystem services across all spatial scales to form a basis for achieving human well-being and sustainable development.

"*There is growing consensus that strengthening the interrelations between science and policy at all levels is necessary (but not sufficient) for more effective governance of biodiversity and ecosystem services. Current environmental problems, often of considerable magnitude and complexity, challenge science, politics, policy and their interrelations in unprecedented ways, confronting them with situations in which facts are uncertain, values in dispute, stakes high and decisions urgent.*" (UNEP/IPBES/2/2 published 2009)

Something pointed out by the group was also that developing and less developed countries have a reduced capacity to fully engage in relevant policy-science interface processes. When developing future research programs this aspect should be kept in mind and should be an incentive to address capacity building in the field of science-policy interface to optimize the usability of research outcomes.

At EU level and in Germany many platforms for policy-science interfaces already exist, but there is still potential to improve. At the 2009 national GLOWA conference on 'Global Change and the Hydrological Cycle' in Potsdam scientists and policy-makers alike expressed the need for improved communication. It is necessary to learn to speak the 'same language', if efficient exchange is to be achieved. Scientific results must be presented in a way that political decision makers and practitioners can make use of the findings for their work. At the same time the framework conditions for science must leave room for this.

Ways to cooperate and share knowledge and experiences must be developed. Short and simplified communication channels enabling direct informal exchange without the constraints of formal institutional structures could offer progress in relation to this. For future research programs it may be advisable to make the policy-science interface an integral part of projects where needed and foster cooperation and exchange throughout the duration of the research program making it a learning experience for all involved.

3.3 Relevance of international policy problem

The urgency of meeting the future challenges of safeguarding ecosystem services in the long-term are widely agreed on. The current status of research and the identified research gaps underline the essential role of social-ecological linkages in achieving sustainable solutions. Accordingly, the relevance for policy-making is undeniable. There are already policies and legislations that address the protection of ecosystem services, but Carpenter et al (2009) point out how some policies and practices attempted to achieve win-win situations benefiting both humans and nature, lack a sound knowledge base and are based on untested assumptions.

Consequently, Carpenter et al (2009) emphasize that it is "imperative for the policy and science communities [to] establish a capacity to create and implement policies for social-ecological systems, predict consequences, and evaluate outcomes". As the ecological and social system are deeply intertwined understanding the underlying processes and dynamics is crucial for policy makers to be able to make informed decisions. Furthermore it must be borne in mind that different policies and actions are needed at different levels (Zehnder 2010). Consequently science must assist policy-makers in identifying what kind of policies and tasks are required at the regional, national or international level. Scientific findings must be operationalized and communicated appropriately. For policy-makers it is important to acknowledge human dependence on intact ecosystem services and explicitly integrate environmental water needs into their policies, especially where the flow regimes vary and where the water needs are linked to water quantity and quality (Baron et al 2002). Additionally, it must be borne in mind that social-ecological linkages are highly context specific and there must be room for adaptations after the evaluation of policies and implemented actions.

3.4 Suitability of the programme to be implemented in the German scientific community

The research needs identified above underline the importance of future research efforts. As social-ecological linkages are of relevance across the different scales from local to global, it is an interesting and suitable field of research for the German scientific community.

Currently, the scientific community dealing specifically with social-ecological linkages is quite international with the USA seemingly occupying a leading role when looking at the sources of scientific publications. Nonetheless, German scientists already have a good standing within this international scientific community and a stronger research focus on specific aspects, e.g. improving the knowledge base on human and environmental water needs or the role of governance in sustainably managing trade-offs, could strengthen the German scientific community considerably.

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Application Area

Management tools for implementation of environmental flows (focussing on stakeholder involvement)

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1. Introduction

Environmental flows are defined in the Brisbane Declaration as the "quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihood and well-being that depend on these ecosystems" (Brisbane Declaration 2007). This definition highlights the importance of environmental flows for the preservation of ecosystem functions and services. Water plays a key role in the landscape system by being central for the survival for all living organisms (Falkenmark and Mikulski 1994). Changes in the water and ecosystem are however not undesirable as such. In fact, changes in an ecosystem are often inevitable if not mandatory for its overall integrity (Holling et al. 2002; Walker et al. 2004). Ecosystems have adapted to site-specific water availability in terms of quantity, variability, and quality through a long-term evolutionary process. Fauna and flora thus heavily depend on the natural flow regime of rivers (see Walker et al. 1995; Power et al. 1995; Poff et al. 1997; Bunn and Arthington 2002; Lytle and Poff 2004). Thus, the alteration of the key variable 'streamflow' induces profound changes in the ecosystem (Bunn and Arthington 2002; Poff and Zimmerman 2010).

The 'ecosystem services' and 'ecosystem functions' concepts address the relation of physical or ecological systems and human values. Ecosystem functions (e.g. soil rentention) are theses ecosystem processes that are used and valued by people, and thereby become ecosystem services (e.g. prevention of damage from erosion) (cf. de Groot 2006; Termorshuizen and Opdam 2009). The Millennium Ecosystem Assessment (MEA, 2005) placed ecosystem services into the categories *provisioning, regulating, cultural, and supporting*. Provisioning services are most clearly recognizable services and provide direct products people can use such as clean drinking water, or fertile land for agriculture and grazing. In respect to freshwater ecosystems, inland fisheries in developing countries may provide the only source of animal protein for rural people (Welcomme et al. 2006). Regulating services like natural purification in wetlands and river ecosystems are often less obvious. The natural flow regime of rivers supports a variety of regulating ecosystem services, such as erosion, pollution, and flood and pest control (Poff et al. 1997). Recreational, spiritual, aesthetic services are examples for cultural services of wetlands. Water in general, and rivers in particular have a special value in the culture and spiritual traditions of indigenous peoples (Craig 2007). Supporting services are necessary for the provision of all other ecosystem services. Their impacts on people are indirect or occur at longer time frames compared to other types of services. Examples are soil formation, nutrient cycling or climate regulation among others (MEA, 2005). Hydrologic alterations also have an impact on these supporting services like nutrient cycling and biodiversity (Pringle 1997, Richter et al. 1998). However, other classifications of ecosystem services exist. Wallace (2007) criticizes the MEA categories as being "not a coherent set of services at the same level that can be explored and traded off in a decision system" (2007, p. 238). For instance, food production (provisioning service) is an end of an ecosystem management process, while pollination (regulating service) is a means of service delivery. He also considers 'ecosystem function' as an ambiguous concept that is not required for the analysis of ecosystem services. Thus, Wallace (2007) proposes an alternative classification scheme that differentiates between ecosystem services, processes and structure.

Before environmental flows can be implemented, flow rules have to be determined using a defensible approach that is based on best-available knowledge. Over 200 methods exist but standard methods are still lacking that allow for defensible and resource-effective assessment. The methods used for environmental flows assessment have developed from simple rule-of-thumb methods for the preservation of commercially important fish species to holistic methods that encompass ecologic as well as socio-economic aspects (Tharme 2003). The Milestone Report of the BMBF-project (Pahl-Wostl et al. 2010) provides an overview of available methods and their history of development (see also: Tharme et al. 2003, Dyson et al. 2003).

Despite extensive development and testing of methodologies, examples for the successful implementation of environmental flow rules are rare (O'Keefe and Le Quesne 2009; Poff et al. 2010). Experts in the BMBF project workshop held in February 2010 in Osnabrück concluded that the main obstacle for of the environmental flow concept to have a real impact is related to the implementation of flow rules. The following topics have been determined to be the scientific and practical challenges in respect to flow implementation that are also reflected in the major findings from recent publications on environmental flows and international conferences in Australia (Garrick et al. 2008) and South Africa (Garrick et al. 2009):

1) The applicability of environmental flow assessment methods depends considerably on the socio-economic context. In addition, the required effort of application varies from simple rules of thumb to data-intensive computer models (O'Keefe and Le Quesne 2009; Poff et al. 2010). The ELOHA framework is a recent approach to meet these shortcomings - a <u>methodological framework for flow assessment at the regional and national scale</u> that aspire general applicability by defining river typologies (Poff et al. 2010). In addition, <u>holistic assessment methodologies</u> are required to examine links and trade-offs between economic, environmental and sociological benefits of environmental flows (King et al., 2003, Korsgaard et al. 2008).

2) The demand for predictive assessment of flow-ecology relationships requires long-term research activities and, thus, can stall implementation of flow rules. <u>Adaptive management approaches</u> for environmental flow assessment regard flow rules as flexible guiding principles that need to be adapted to new insights derived from experiments instead of definite standards. In case of limited knowledge, controlled experiments allow for learning about flow-ecology linkages that needs to be monitored and iteratively refined (Poff et al. 2003; Richter et al. 2006; Garrick et al. 2008, and 2009).

3) Implementation of flow rules depends upon the commitment of stakeholder groups towards measures or policies. Ecosystem services need to be valued by stakeholders including scientists, policy makers, water users and interest groups. Therefore, methods for <u>stakeholder involvement</u> in the valuation of ecosystem services as well as setting and implementation environmental flows are needed (O'Keefe and Le Quesne 2009; Garrick et al. 2008, and 2009). The operation of technical infrastructure (e.g. dams) to sustain or mimic a natural flow regime is another impediment towards successful implementation (Richter and Thomas 2007; Garrick et al. 2008, and 2009).

4) <u>Water governance</u> reforms are needed to find effective institutional structures to assure implementation of environmental flows and preservation of ecosystem integrity (Garrick et al. 2008, and 2009). Research on governance of environmental flows includes legislative (e.g. property rights), economic (e.g. water markets), and social aspects.

2 Recent trends in environmental flow research

The following section will review recent developments concerning all main impediments identified for the implementation of environmental flows. A special focus will be devoted to methods and frameworks that address participatory research on environmental flows.

2.1 Methodological framework for flow assessment at large scales, and holistic methods for integrated flow assessment

The threat of over-allocation of rivers is rising due to the accelerating pace of global and climate change (cf. Palmer et al. 2008). Water management has to deal with an increasing uncertainty that demands innovative approaches to deal with societal pressure on ecosystems (Pahl-Wostl, 2007). Understanding the linkage of environmental flow regimes to ecosystem functions and further to environmental services is a complex task that requires in depth empirical research to generate reliable knowledge and flow standards. However, long-term scientific research is often not possible as resources are often limited, and water management demands timely results (Hanssen et al. 2009). The use of 'rules of thumb' is one approach to come to quick results with limited resources. Flow standards are therefore calculated by using fixed percentages of flow components like the median annual flow, base flow, or surface runoff (e.g. Cullen 2001; Smakhtin et al. 2004). These simplistic and static approaches are more and more criticized as they ignore the full complexity of the natural system and are not based on empirical research (Richter et al. 1996; Poff et al. 1997; Lytle and Poff 2004; Arthington et al. 2006). Given the resource intensity of quantitative assessment methods, Poff et al. (2010) argue that a river-by-river assessment of environmental flows will not keep pace with global and climate change, even though methodological knowledge from individual case studies is advanced. They propose the synthesis of existing knowledge into a scientific framework for the assessment of environmental flows at larger scales, namely regional up to national scales. This generic approach comprises the identification of classes of natural rivers in a region based on ecological responses to flow alteration (cf. Artington et al. 2006). Impaired rivers are sorted in these classes by estimating the pre-disturbance flow metrics or applying landscape or climate characteristics. The framework builds on the notion that flow-ecological relationships are not necessarily exclusive to single rivers but may be applicable to rivers of a particular hydrological type (such as unpredictable rain-fed perennial rivers or seasonally predictable snowmelt rivers) (cp. Poff, 1996). A class represents a "management unit" and provides a guideline for the implementation of environmental flows based on empirical knowledge gained in other rivers belonging to the particular class. Quantitative relationships between flow-alteration and ecological response have to be developed along the gradient of natural to impaired river flow regimes in order to be able to set environmental flow standards. Thus, flow rules can be tailored to management goals about the status of rivers ranging from the preservation of natural flow regimes, to restoration of highly modified rivers (Artington et al. 2006).

Another important methodological development is related to holistic environmental flow assessment methods that incorporate hydrological, hydraulic and habitat simulation models (Dyson et al. 2003). The origin and application area of methods is quite diverse with the Instream Flow Incremental Methodology (IFIM) developed in the US (Bovee, 1986; Bovee et al., 1998), the Holistic Method mostly applied in Australia (Arthington et al. 1992, Arthington 1998), and the Catchment Abstraction Management Strategies (CAMS) from the UK Environment Agency (DETR and Welsh Office. 1999). The DRIFT methodology (Downstream Response to Imposed Flow Transformation) originates from South Africa, and is the only method that includes societal consequences of flow alteration. It bases on the Building Block Method (BBM) (King and Louw, 1998; King et al., 2000), and consists of four modules: a biophysical, socio-economic, scenario as well as economic module (King et al., 2003). A common feature of holistic methodologies is the incorporation of knowledge from a range of disciplines through expert panels and/or the initiation of public participation processes (Dyson et al. 2003). Scenario analyses allow for analysis of consequences of flow alteration that can support decision-making on the desired state of a river and the related flow regime (King et al., 2003). Koorsgard (2006) developed a Service Provision Index (SPI) that constitutes a modification of socio-economic module of the DRIFT methodology. The SPI links ecosystem services to flows, and thus allow for the valuation of environmental flows (Korsgaard 2006, Korsgaard et al. 2008).

2.2 Adaptive management approach

An adaptive management approach is promoted by various scholars as a meta-framework to allow for immediate management action under situations of incomplete knowledge on flow-ecology relationships, for instance due to knowledge gaps, limited resources or time-pressure (e.g. Richter et al. 2006, O'Keefe and Le Quesne 2009).

Holling (1978) describes the adaptive management approach as "an integrated, multidisciplinary and systematic approach to improving management and accommodating change by learning from the outcomes of management policies and practices". Using an adaptive management approach, environmental flow rules are considered as hypotheses rather than ultimate truths. This understanding fosters learning about the water system through iterative improvement of environmental flow rules. Thus, controlled experiments with environmental flows can provide valuable insights about the responses of riparian ecosystems (Poff et al. 2003). Richter et al. (2006) developed a collaborative and adaptive management framework for the setting of environmental flow recommendations. Even though the application of data-intensive simulation models is explicitly considered to be important for the understanding of flow-ecology linkages, the framework applies exclusively conceptual qualitative models to highlight that adaptive management of environmental flows does not necessarily depend on quantitative modelling. The 5-step process comprises: (1) an orientation meeting in which scientific, political and other stakeholders meet to discuss the organization of the overall process, and define sources of data relevant to the flow assessment; (2) preparation of a literature review and summary report that contains existing data and knowledge on the water system; (3) a flow recommendation workshop held by scientists from multiple disciplines to quantitatively define environmental flow rules based on collected information; (4) implementing the recommendation and monitoring of effects through a carefully designed monitoring programme including gauges and ecosystem indicators; and finally (5) initiation of data collection and research programs that evaluate the outcomes of the implemented flow rules and gaps in knowledge and data. The steps 3-5 are continuously implemented to improve knowledge on the hydro-ecological system and refine environmental flows.

Acreman and King (2003) outlined a 10-step strategy for capacity building in Tanzania which contains also elements of general relevance (see Dyson et al. 2003). They propose an adaptive management approach through testing of flow assessment methods and implementation through a case study in a high-conflict area. In addition, cooperation between experts from different disciplines as well as international cooperation and field visits to learn from others' experiences are considered to be important. Further steps contain the instalment of a national database of knowledge on environmental flows, as well as a communication strategy to spread information to all relevant sectors and the public (Acreman and King 2003).

Besides being an experimental approach, adaptive management strives for the increase of adaptive capacity of human-environment systems (Baron et al. 2002; Pahl-Wostl 2007). Adaptive capacity can be defined as "the ability of a socio-ecological system to cope with novelty without losing options for the future" (Folke *et al.*, 2002). In respect of environmental flows, the Ecohydrology concept from the UNESCO aims at the purposeful usage of ecosystem processes to fulfil water-related services for society. Thus, water management can make use of ecosystem properties as natural infrastructure similar to engineering approaches to fulfil its goals (Zalewski 2002). Through protection of ecosystem functions, the capacity of the ecosystem rises to absorb human impacts. For instance, wetlands can play an important role in denitrification processes originating from the application of fertilizers in agriculture (Zalewski 2000). 'Natural infrastructure' is a similar concept that demand research on ecosystem functions and related services to allow water management to implement the most effective set of technical and conservation measures (Smith and Barchiesi, 2009).

In addition to enhance the adaptive capacity of ecosystems, adaptive management lays particular importance on collaborative management that includes multiple stakeholder groups. Social learning increases the adaptive capacity of stakeholder groups that can be defined as the ability to react to problems through informal learning processes and collective action (Pahl-Wostl et al. 2007). However, participatory approaches in environmental flow assessment are rare. Literature dealing with adaptive management approaches place more emphasis on experimental component of adaptive management than on stakeholder involvement. The next section provides a review of participatory management tools for environmental flow assessment and implementation.

2.3 Participatory management tools

The environmental flow requirement in a river system is often a negotiated trade-off between multiple water users including the environment (Naiman et al. 2002). Although the need for stakeholder involvement in this negotiation process has been highlighted quite often (e.g. Poff et al. 2003; Rogers 2006; O'Keefe and Le Quesne 2009; Smith 2009), only a limited number of articles provide concrete approaches that specify the form and organization of stakeholder involvement. Experiences with the implementation of the WFD have shown that stakeholder involvement needs to be well-planned to avoid frustration, for instance in case that real participation in decision-making is promised but only information or consultation realized (Acreman and Ferguson 2010).

The research and implementation process of environmental flows provide different opportunities for participation, and can be divided into the following steps:

1) Definition of objectives for water management, and valuation of services provided by the water system

2) Analysis of ecosystem services – environmental flow relationships

3) Strategy development and implementation of environmental flows

4) Monitoring of effects of flow alteration, and strategy revision

An overview of participatory approaches concerning these steps of flow assessment and implementation is provided in the following sections.

2.3.1 Setting objectives and valuation of ecosystem services

To be accepted and effective, environmental assessments need to be incorporated in a basin-wide water management process. The definition of objectives for river management constitutes a social judgement that implies the valuation of services provided by the aquatic ecosystem. Thus, water management in general and environmental flow assessment in particular require the participation of multiple stakeholders comprising scientists, politicians, water users, and other affected groups (Poff et al, 2003; Rogers 2006; O'Keefe and Le Quesne 2009; Smith 2009).

The overall objectives for water management are often predetermined by water legislations. In South Africa objectives are set according to ecological management targets (Rogers and Bestbier 1997), and the EU WFD demands a good status of all water bodies (EC 2000). However, the transfer of these more general targets to specific and operational management goals permits the involvement of stakeholders.

The “objectives hierarchy” is a method that helps to connect aims and visions of non-specialist stakeholders with the often more technical knowledge of experts (O’Keefe and Le Quesne 2009). The process starts with the development of a vision statement that expresses the goal of river management by the stakeholder group. This often more general and unspecific vision is afterwards translated to a high-level objective that includes operational goals for water managers. Finally, sub-objectives and measureable indicators are determined to further specify management goals. A complementary approach is the "thresholds of potential concern” concept that sets upper and lower limits to operational indicators (Biggs and Rogers, 2003). In case of reaching a threshold level, a predetermined management response is applied comprising the analysis of causes, and the implementation of countermeasures.

Ecosystem functions and services that are provided by riverine ecosystems are manifold (see MEA 2005). Economic methods for the monetary valuation of ecosystem services are widely applied. Forslund et al. (2009) provides an overview of methods and their potential and limitations to be used for environmental flow assessment. Despite various shortcomings of economic methods for valuation, they conclude that each method has the potential to raise awareness about roles and values of ecosystem services. The choice for ecosystem services and functions/processes to protect or restore requires the involvement of beneficiaries of services as well as individuals and organizations whose actions impair their provision (Chee 2004). In addition to a clear vision about desired ecosystem services, Chee (2004) suggests an adaptive approach that includes learning about the problem and dynamics of the system resulting from the application of different measures. Risks and uncertainties involved have to be assessed, and a discussion about solutions and trade-offs between stakeholders facilitated. The combination of tools like discourse-based methods, simulation modelling, probabilistic risk assessment, multi-criteria analysis, and scenario planning are approaches that can facilitate participatory processes dealing with the valuation of ecosystem services (Chee 2004). The DRIFT methodology (King et al., 2003) fulfils most of these demands, especially in combination with the Service Provision Index (SPI) developed by Korsgaard (2006) (see section 2.1). The aim of the DRIFT methodology to predict future developments of human-technology-environment systems complies with the traditional command-and-control paradigm in water resources management. However, adaptive management approaches are more suitable to deal with inherent complexity of the system to be managed (Pahl-Wostl 2007). Thus, soft systems methods and group model building techniques could be suitable and innovative methodological approaches for environmental flow assessment.

2.3.2 Analyze flow-ecology relationships

While the valuation of ecosystem services is a social process, the study of ecosystem functions that produce these services requires a scientific approach. Various scientific methods exist for the assessment of impacts of flow alteration on the ecosystem (see Dyson et al. 2003; Tharme 2003; Arthington et al. 2006). Even though the analysis of flow-ecology relationships are more a scientific task, the specification of flow rules requires the assessment of risks and trade-offs that, in turn, makes the inclusion of the public in the decision-making process necessary. Participatory methods for the definition of environmental flow rules are rare. One example is the "flow-response graph" that helps to define acceptable and adverse resource impacts (Poff et al., 2010).

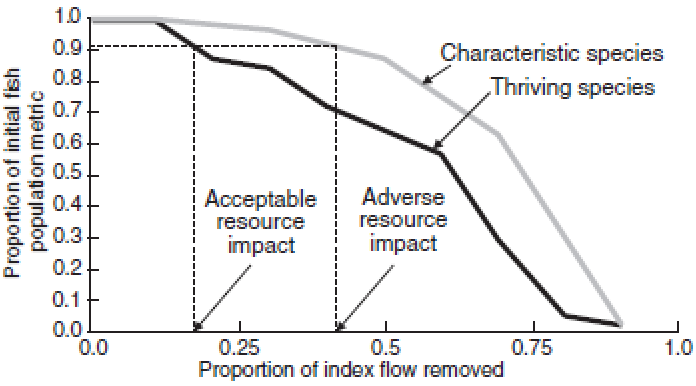

Figure 1: Progression from flow alteration–ecological response relationships to environmental flow standards (Poff et al. 2010, modified from MGCAC, 2007).

Figure 1 illustrates the dependency of the fish population (differentiated between thriving and characteristic species) on allocated water for a stream type in Michigan, USA (MGCAC, 2007). A stakeholder committee decided that a 10% decline in the thriving population is an acceptable impact, while a 10% decline in the characteristic population is an adverse impact. Based on these definitions, environmental flow rules can be derived for operational management by selecting the corresponding flow alteration on the x-axis (Poff et al. 2010).

2.3.3 Strategy development and implementation of environmental flows

The application of participatory methods is considered to increase commitment of stakeholders towards the implementation of flow rules rather than top-down decision-making. However, a concerted strategy of technical, economic, and political measures is necessary to achieve flow targets.

In modified river basins, the installed infrastructure can impede the implementation of environmental flows. For instance, the outlets of dams may restrict the maximal volume of flows (O'Keefe and Le Quesne 2009). New dam designs need to consider environmental flows as later re-operation are costly and sometimes even impossible. In addition to the technical design, structures like roads and houses as well as high-value agriculture can impede the implementation of high flows. Low flows can also be inhibited in case that high flow volumes are required for the dilution of wastewater (Richter and Thomas 2007).

Impoundments such as dams or weirs have been constructed for many purposes - like water supply hydropower generation, or flood control – while the assurance of environmental flows was seldomly considered (Dyson et al. 2003; Acreman et al. 2009). Thus, dams usually involve major changes in the natural flow regimes up to total elimination of the natural variability. This caused a widespread impairment of riverine ecosystems and ecosystem services provided (WCD 2000; MEA 2005). In the UK and similarly in France and Brasil, most of the dams (about 70%) constantly release about 16% of the mean flow throughout the year. Only a few dams realize variations of the flow release, while other impoundments regularly do not release any volumes at all (Acreman et al. 2009). Richter and Thomas (2007) provide a framework for the assessment of potential benefits that can be restored through dam re-operation. Effective strategies for dam re-operation also have to include the distribution and usage of benefits from dam operation as well as socio-political and economic drivers. They suggest the inclusion of stakeholders in the setting of specific and short-term goals for water management as well as dam re-operation. However, dam re-operation is not possible in all cases as environmental flows are just one aspect of dam regulations, and redesign can reduce profitability of other services (Dyson et al. 2003).

Other limiting factors for flow implementation belong to legislative, economic, or social aspects. Holistic methods allow for an interdisciplinary analysis of consequences caused by flow allocation rules (see section 2.1). In particular the sociological dimension as well as governance of environmental flows requires further research. While the aspects of the former is already included in the DRIFT methodology (King et al. 2003), governance of environmental flows mainly deals with economic aspects and instruments. Further details on the governance of environmental flows are given in section 2.4.

2.3.4 Monitoring and revision

Monitoring is an integral step of adaptive management to learn from past actions and thereby iteratively improve measures. An effective monitoring network should reveal unintended and unforeseen trends and thus induce a rethinking and reassessment of implementation strategies and underlying assumptions.

Monitoring of environmental flows has two purposes: first, to control the implementation of flows at several points of a river, and second monitor the achievement of a desired condition, for instance, in respect to ecology, or geomorphology (King and Brown 2006). To assure the effective learning from implementation, suitable hypotheses and indicators for monitoring has to be predefined. As described above in section 2.3.1, the objectives hierarchy and Threshold of Potential Concern (TPC) are methods to find and evaluate operable indicators that are linked to overall management goals (Rogers and Biggs 1999).

Another important task besides the implementation of measures is the definition of knowledge gaps that require further research. The participatory process as well as monitoring can reveal case-specific and practical research needs that guide the work of the scientific community (Acreman and King 2003; Richter et al. 2006).

2.4 Water Governance

'Governance' can be defined as coordination and steering processes regulated by formal and informal institutions to influence behavior of agents (Scharpf, 1997). A possible classification of governance processes is the distinction between hierarchical bureaucracies, markets, and networks (e.g. Thompson et al. 1991). These modes differ in respect to their formality and actors involved (Pahl-Wostl 2009). Hierarchical bureaucracies comprise regulatory processes based on formal institutions (e.g. legislation) that are performed by governmental agencies. Market governance is based on a combination of informal and formal institutions, and is dominated by non-state actors. Networks allow the involvement of non-state as well as governmental actors in an informal institutional setting. Experienced limitations of top-down governance systems and exploratory empirical analyses provide evidence that combinations of different governance modes result in more adaptive and thus more effective governance regimes in the face of climate and global change, rather than the dominance of one single governance mode (Pahl-Wostl 2009). Research on multi-level and multi-actor resource governance regimes is an innovative field. Similar to the topic of environmental flows, simplistic as well as detailed approaches for the analysis of governance regime have been developed. While institutional panaceas devised by simplistic approaches turned out to be not useful or even detrimental (Ostrom, 2007; Ingram, 2008), detailed analyzes are too resource intensive to be applied on a case-by-case basis, and make generalizations difficult. Thus, a diagnostic and systemic approach of intermediate complexity is more promising for the analysis of resource governance systems to allow for transfer of findings across cases (Pahl-Wostl 1995; Ostrom 2007; Young 2007). Applications of this approach have been realized for resource governance (Ostrom 2007; Young 2008) as well as more specifically for water governance regimes (Pahl-Wostl 2009).

Research on governance of environmental flows from a more general, rather than context-sensitive, perspective is lacking. Legislative requirements for the consideration and implementation of environmental flows are diverse around the globe. Research on the implementation of environmental flows in legislation already exists but is restricted to specific pieces of legislation like the EU Water Framework Directive (Acreman et al.2009; Acreman and Ferguson 2010). Water markets are an often promoted solution to achieve efficient water allocation and redistribution of water. Different forms of water markets exist that are open markets, spot markets, administrative water trading, and informal water markets (Le Quesne et al. 2007). Australia has often been referred to as an example for the network mode of governance even though market and hierarchical elements are important aspects in Australian water governance as well (Bell and Park 2006; Bell and Quiggin 2008). Due to the interplay of all governance modes, research on governance of environmental flows is needed to detect general attributes of effective governance regimes and learn from the comparative analysis.

3 Assessment of future trends and research needs

Based on literature review (see chapter 2), future trends and research needs are assessed below in respect to knowledge gaps, science-policy interplay, relevance of the problem, and suitability to be implemented in the German research community.

3.1 Gaps in scientific knowledge and potential to achieve scientific breakthroughs

This application area report focuses on management tools for the implementation of environmental flows. Scientific knowledge on environmental flows for individual cases has been determined to be quite developed while the implementation runs far behind (O'Keefe and Le Quesne 2009). Nevertheless, gaps in scientific knowledge exist too, and have been outlined in the Milestone Report of the BMBF-project (Pahl-Wostl et al. 2010). In the following, these knowledge gaps are listed (gaps 1-3) and complemented with research needs for the implementation of environmental flows (gap 4):

1) *Lack of knowledge about fresh water status*

A comprehensive global analysis of freshwater biodiversity comparable to those recently completed for terrestrial systems is lacking as well as a basic global mapping of inland waters, classified by broad geomorphic categories and an assessment of anticipated changes of lakes, rivers and wetlands (Dudgeon et al. 2005). Since then, a synthesis of biodiversity data for ecoregions has been produced by the Freshwater Ecoregions of the World project (Abell et al. 2008), produced by World Wide Fund for Nature and the Nature Conservancy. Another source for information about freshwater status is FishBase, which compiles fish data from around the globe (www.fishbase.org).

2) Lack of quantitative knowledge about flow−ecology links

A substantial literature review on flow-ecology relationships has been carried out by Poff and Zimmermann (2010). They concluded that existing data were not sufficient to develop general and transferable flow-ecology relationships, and emphasized that “new sampling programs and analyses that target sites across well-defined gradients of flow alteration are needed to quantify ecological response and develop robust and general flow alteration–ecological response relationships.” (p. 195). This general knowledge on environmental flows is needed for different river types to be applicable for larger scales like regions or nations (Poff et al. 2010). Sophocleous (2007) identifies a number of knowledge gaps relating to groundwater in environmental flow assessments. These gaps specifically concern rudimentary knowledge about groundwater-dependent ecosystems, aspects of streamaquifer interactions, and the impacts of land-use changes.

3) Lack of quantitative knowledge on the importance of freshwater ecosystem services for human livelihood

Several methods for the identification, recognition, and valuation of the ecosystem services exist but need for further research on to how to best mainstream such valuations into environmental flow assessments and water management decisions. Forslund et al. (2009) discuss the links between environmental flows and human livelihood in a Swedish Water House report entitled “Securing water for ecosystems and human well being; the importance of environmental flows”.

4) Difficulty of implementation of environmental flows in water management

There are different obstacles that impede the implementation of environmental flow rules.

First, a high number of methods are merely applicable in a specific context (Poff et al. 2010). The data requirements for their application vary considerably from simple “rules of thumb” to data-intensive simulation models. Thus, more generic and large scale methods are needed to cope with the increasing pressure on freshwater ecosystems. In this respect, the ELOHA-framework from Poff et al. (2010) is an innovative approach by developing river typologies that can be applied for regional or national flow assessment.

Second, holistic methods are required that are able to assess social, economic and environmental consequences of flow alteration, and allow for the balancing of trade-offs. The DRIFT methodology (King *et al*., 2003) is an innovative approach which however requires further development, for instance in respect to the consideration of a broader set of social aspects.

Third, adaptive management approaches assure a timely implementation of environmental flows, and to deal constructively with incomplete knowledge and data about flow-ecology linkages. First frameworks for adaptive management processes have been developed for environmental flow assessment (Richter et al. 2006). However, linkages to general water resource management processes and concepts like integrated and adaptive water resources management are required to set environmental flows higher on the water management agenda.

Fourth, participatory approaches are needed to increase commitment to flow rules, develop holistic strategies to coordinate measures and engagement of actors, and allow for social judgement on ecosystem services. In relation to the existence of over 200 methods for the assessment of environmental flows, the number of participatory tools is very low (cf. section 2.3). Further research and testing of participatory methods and tools will be required to assess consequences of flow alteration and related ecosystem services and risks.

Fifth, the design and operation of technical infrastructure can be an impediment for the implementation of environmental flows in case of modified rivers and related wetlands. Innovative approaches are needed that help to consider flow rules in the design of impoundments, and re-operation of installed structures. Furthermore, strategic approaches are lacking that combine these technical aspects with economic and social measures.

Sixth, water governance is another aspect that requires further research. Several institutional barriers to flow reallocation were identified, such as unclear property rights, high political and economic costs, and weak institutional capacity. Existing legislation frameworks concerning water management may also be a hindrance towards implementation (Garrick et al. 2009). The analysis of barriers to and drivers of environmental flow implementation in governance regimes is thus an important research topic.

In general, environmental flows are an international visible and relevant research field, having a long history that can be dated back to the late 1940s. The existence of about 207 individual methodologies on environmental flow assessment in 44 countries within six world regions demonstrates the practical relevance of the topic and its widespread application (Tharme 2003). A Scopus-analysis revealed that the number of publications on 'environmental flows' increased by nearly five times in the last 10 years, demonstrating the growing importance of environmental flow research (see Table 1). The sub-themes participatory and adaptive management, and flow implementation show an increasing tendency, too. The number of publications for the term 'environmental flow' quadruplicated, while participatory approaches increased from zero in 1999 to 10 publications in 2009 (see Table 1). Publications on management or implementation of environmental flows have even increased by the factor 40. The links of ecosystem services and governance to environmental flows have had minor relevance in scientific publications during this time frame despite the special importance of these topics (cf. section 2.3).

Table 1: Quantitative Scopus analysis (1999-2010)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
„Environmental Flow"	16	17	24	17	40	22	45	47	43	71	68	31
„Environmental Flow" AND participation OR stakeholder OR communities	0	2	1	2	8	4	4	5	4	10	10	8
„Environmental Flow" AND adaptive OR adaptation	1	0	0	3	3	0	1	2	2	2	2	7
"Environmental flow" AND implementation OR management	1	3	8	9	20	11	20	22	13	34	40	19
"Environmental flow" AND "ecosystem service"	0	0	0	0	0	0	0	0	0	2	0	2
"Environmental flow" AND governance	0	0	0	0	0	0	3	0	0	0	1	0

Number of publications (choice for search space "article or review") with "Search term" in title, abstract or key words.

An analysis of the division of articles and reviews into disciplines clearly demonstrates the dominance of the natural sciences in environmental flow research in the last ten years (see Table 2). Publications are related about three times more often to the natural sciences than to the social sciences and engineering disciplines.

Table 2: Scopus results related to natural, social and engineering sciences

Search term "Environmental Flow"

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Natural Sciences	13	16	24	15	37	22	39	43	41	68	64	32
Social Sciences	1	1	1	2	4	0	1	5	5	5	13	3
Engineering Sciences	3	1	2	3	5	1	13	7	7	10	10	2

(the total amount of publications given for each year exceeds that for the search terms in Table 1, as articles and review papers can be related to multiple disciplines)

This relation between the disciplines has been stable during the last ten years as can be seen in the diagram below showing the Scopus-results related to the base year 1999 (see Figure 3). In 2009, publications in the social sciences jumped up to the factor 13 which could be an indication for a higher emphasis on the social dimension of environmental flow research in the near future.

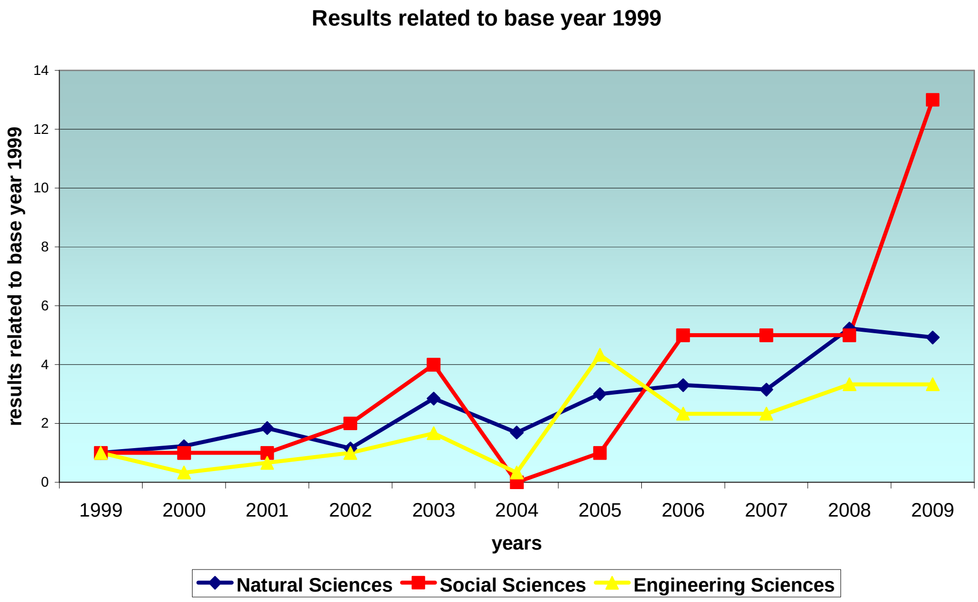

Figure 3: Illustration of division of Scopus results into natural, social and engineering sciences related to the base year 1999.

The high relevance of environmental flows in research and practice is reflected in the program of major scientific and political conferences on water. At the World Water Week 2009 in Stockholm, two seminars and one workshop were explicitly related to environmental flows implementation as well as the linkage to sustainable development, poverty alleviation, biodiversity conservation, and integrated water resources management (see Appendix II). ‘Environmental flows’ also has been a prominent topic at the World Water Forum 2009 in Istanbul. It was raised in two out of six thematic areas as well as the political process. Integrated approaches for flow assessment have been discussed at the World Water Forum including stakeholder participation in the investigation, valuation and management of multiple use and functions of water services. Other important topics have been flow indicators, and environmental flows as a central measure to balance human and ecologic needs (see Appendix III).

Due to the high political and scientific relevance of environmental flows, large international programs on environmental flow assessment and implementation exist. Research initiatives are conducted by the International Union for Conservation of Nature (IUCN), the International Water management Institute (IWMI), and the International Hydrological Programme (IHP) of the UNESCO. On the national level, the Swedish Environmental Flows Initiative reflects the importance of the concept for national water practice and research (Forslund et al. 2009). In the eFlowNet-database of projects and case studies on environmental flows, only river-specific projects are indicated. From these 26 registered projects and case-studies, 16 entries are related to the category ‘engineering (hydropower and irrigation)’, 5 to ‘assessment and evaluation’, 2 to ‘ecology and biology’ (Fish, Invertebrates, Aquatic plants), 1 to ‘economics’ (valuation, payments for ecosystem services, livelihoods), 1 to ‘social’ (human well-being, cultural issues, communities, health, 1 to ‘geomorphology’ (sediment transport) and none to categories that also have been identified to be related to major knowledge gaps: ‘governance’ (institutional structures, stakeholder participation), ‘IWRM and river basin management’, ‘monitoring and implementation’, ‘policy and law’, and ‘tools and methods’. These results reflect the more technical and case-specific focus of environmental flow research.

As highlighted at the World Water Forum 2009, an interdisciplinary approach is needed to study the interplay between terrestrial ecosystems, landscapes and the water cycle, as well as operationalization of the findings of this research for policy and management on national and local scales (see Appendix III). Research on environmental flows is needed that combines knowledge from the natural sciences with those from social and technical disciplines. This will improve the ability of holistic assessment of flow rules and detection of integrated strategies for implementation in an IWRM framework.

Given the knowledge basis on flow-ecology linkages and multitude of flow assessment methods, the obstacles of interdisciplinary and participatory research are surmountable. Further research can build upon established concepts and findings as well as knowledge from other research areas, like integrated and adaptive water resource management, or water governance.

3.2 Science-policy interplay

The topic of environmental flows has a high relevance to multiple stakeholder groups. These include governmental agencies and water managers that are in charge of water resource management or environmental protection. Water user groups have a similar interest in the topic as allocating water for environmental flows can have affects on the water availability for different uses. For instance, environmental flows can have a limiting effect on economic activities (e.g. reduced quantities for irrigation in agricultural sector) as well as supportive effects (e.g. habitat for commercial fish). The general public need to be included for the valuation of ecosystem services and well as evaluation of risks that come along with deviations from the natural flow regime of the river.

The assessment and implementation of environmental flows are urgent tasks for various freshwater ecosystems around the world. Straightening of river beds and construction of impoundments have been realized in many river basins around the globe. This caused degradation of riverine ecosystems and related ecosystem services (WCD 2000). At the same time, many natural rivers are still threatened to be modified by human impacts. Environmental flow assessments have not been conducted for many rivers, and new approaches are needed to assure time and resource effective assessments and implementation.

Water plays a key role in the landscape system (Falkenmark and Mikulski 1994). This determines the management of environmental flows to be an integral aspect of river basin management and landscape planning. Impacts of global change, like increased exposure to floods and droughts, are predominantly linked to the water system (Lehner et al. 2006; Smith and Barchiesi 2009). Thus, the concept of environmental flows can support the management of complex landscape ecosystems by providing a key variable that influence ecologic processes at large scales. In this respect, Dyson et al. (2003) suggest the recognition and usage of environmental flows as a water resources management tool.

The implementation of the Water Framework Directive is an ultimate and relevant policy problem that can be addresses through research on environmental flows. Even though environmental flows are not stated explicitly in the directive, it is accepted that the hydrological regime is central for achieving a good status for all water bodies (Acreman and Ferguson 2010).

Given the high international relevance of the problem, German and European research efforts can have a wide-spread impact. The Water Framework Directive constitutes an innovative piece of water legislation, and thus, provides an unique context to apply research on environmental flows combined with empirical analysis and participatory processes in European river basins. In addition to river conservation, river restoration processes, for instance for heavily modified water bodies, need to consider environmental flows to be effective. The concept of environmental flows particularly facilitates the design and implementation of concerted technological, social and economic measures for the achievement of a good ecological status.

3.3 Relevance of international policy problem

The problem of ecological, morphological and biological degradation of rivers is a major problem which severity is increasing. Climate change is likely to lead to thermal and hydrological changes that aggravate the situation in many of the world’s river basins (Malmqvist and Rundle 2002) while instantaneously global water demand for society and economy is expected to increase (UNEP 2007). All these aspects demonstrate the need to find innovative ways to satisfy human demands while at the same time protect the functioning of ecosystems and related services. Forslund et al. (2009) highlight the important role of environmental flows in climate adaptation strategies.

As a reaction to these problems, many water legislations around the world demand protection and improvement of riverine ecosystems, and a key role of stakeholder involvement in this process. In most of the cases, environmental flows are not stated explicitly in the national water legislations. Examples for the specification of approaches for the management of environmental flows are the definition of minimum flows in the Swiss Water Protection Act, regulated management for the provision of environmental benefits in the Australian Murray Darling Basin, and statutory management plans that demand a requirement for environmental flows in the South Australian Water Resources Act. The South African Water Act applies a combination of the techniques mentioned above to allocate water for ecosystems (Dyson et al. 2003). From a social perspective, environmental flows are important policy instruments for poverty alleviation (e.g. King et al. 2003) and achievement of the Millennium Development Goals (Forslund et al. 2009).

3.4 Suitability of the program to be implemented in the German scientific community

When it comes to the application of environmental flow methodologies, the USA runs far ahead of other countries. Tharme (2003) counted the application of 77 methodologies in the USA that reflects the high priority and long history of environmental flow assessments. Australia (37), the UK (23), Canada (22), South Africa (20), and New Zealand (20) are in a leading position as well (Tharme 2003). However, all reported cases in Europe add up to 122, demonstrating the importance and relevance of environmental flows methodologies in Europe. Germany with 8 published applications resides in the average in Europe (own calculations based on Tharme 2003).

An analysis of scientific publications has been conducted on research fields that were determined to be most important for the implementation of environmental flows. In this analysis, the nationality of authors' affiliations of detected publications was determined from the ISI Web-of-Science database to examine the strengths of national research communities in the research fields of hydrological sciences, water governance, participatory water management, adaptive water management, and environmental flows. Table 3 shows the results that demonstrate an excellent position in the top-5 for Germany in the field of water governance, participatory approaches and adaptive water management, and also a leading position in hydrological sciences (rank 6). With eight scientific publications, Germany resides in the top-10 of environmental flow research. The gap towards the leading nation Australia is considerable though (124 publications).

Table 3: Number of publications on selected search terms in the ISI Web-of-Science database, ranked by the nationality of authors' affiliations

Topic		Hydrological Sciences	Water Governance	Participatory water Management	Adaptive Water Management	Environmental Flows
Search Term(s)		hydrology	water AND governance	water management ANDparticipation	water management AND (adaptive OR adaptation)	"environmental flows"
Rank	1	USA (5,888)	USA (157)	USA (206)	USA (379)	AUSTRALIA (124)
	2	CANADA (1,188)	ENGLAND (93)	ENGLAND (69)	AUSTRALIA (111)	USA (69)
	3	ENGLAND (1,103)	AUSTRALIA (48)	AUSTRALIA (57)	CANADA (93)	ENGLAND (23)
	4	FRANCE (835)	**GERMANY (35)**	**GERMANY (53)**	ENGLAND (84)	PEOPLES R CHINA (21)
	5	AUSTRALIA (766)	NETHERLANDS (35)	NETHERLANDS (50)	**GERMANY (80)**	SOUTH AFRICA (15)
	6	**GERMANY (658)**	CANADA (34)	SOUTH AFRICA (40)	NETHERLANDS (65)	CANADA (14)
	7	NETHERLANDS (530)	SOUTH AFRICA (26)	CANADA (38)	FRANCE (44)	NETHERLANDS (10)
	8	PEOPLES R CHINA (389)	FRANCE (21)	INDIA (35)	SPAIN (43)	**GERMANY (8)**
	9	ITALY (356)	PEOPLES R CHINA (18)	FRANCE (27)	SOUTH AFRICA (36)	FRANCE (7)
	10	SWITZERLAND (287)	SPAIN (18)	PEOPLES R CHINA (26)	PEOPLES R CHINA (34)	JAPAN (7)

These results show the high potential for the German research community to take a leading position in the field of environmental flows. In particular, collaborations between scientists from water governance, as well as participatory and adaptive water management with the environmental flow research community are promising to secure and strengthen Germany's leading position, and develop innovative approaches for the assessment and implementation of environmental flows.

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Manipulating flow and water bodies for managing ecosystem services

Results of Scopus analyses

(www.scopus.com)

Stella Boese

The analysis explores the development of publications and specific trends in every Application Area for the past 10 years. The results comprise the search terms and number of hits in the title, abstract or keywords in the category "articles and reviews". Tables and Figures for each Application Area are listed below.

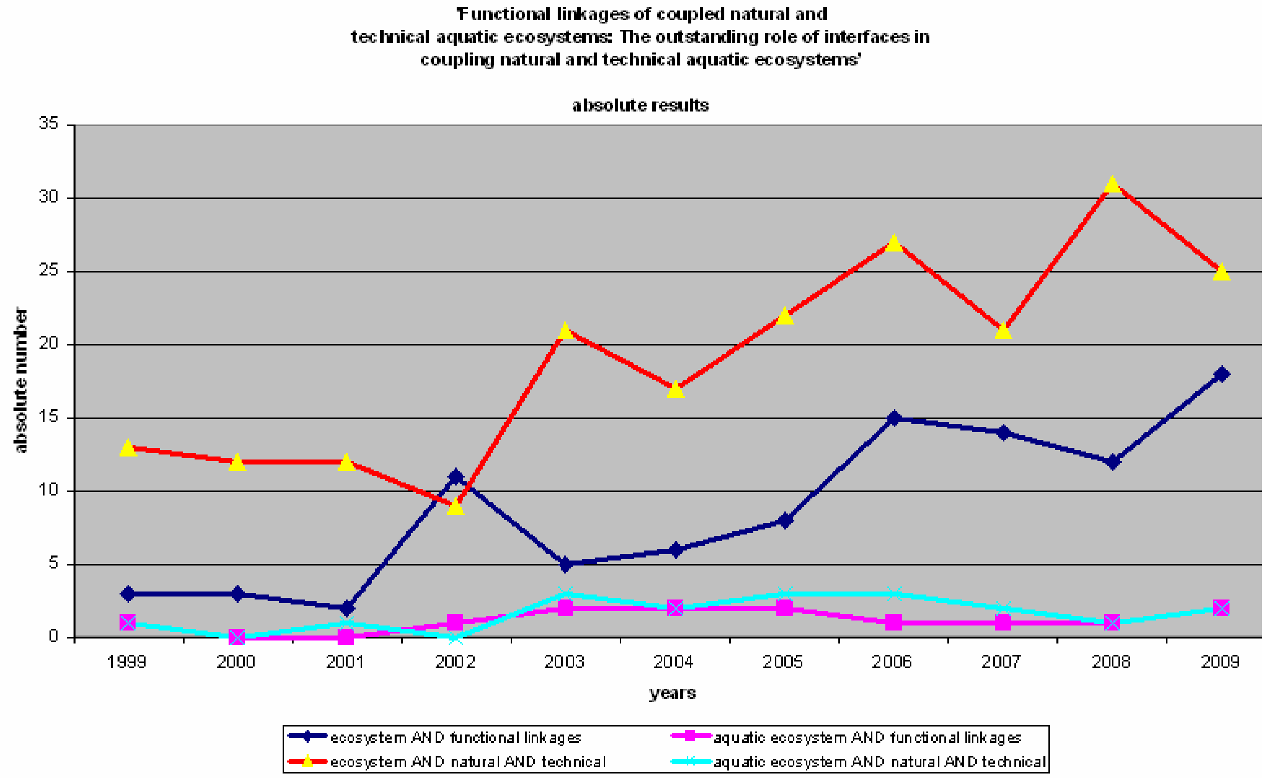
Application Area 1: Functional linkages of coupled natural and technical aquatic ecosystems (rural-urban linkages)

Absolute Numbers

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
ecosystem AND functional linkages	3	3	2	11	5	6	8	15	14	12	18
aquatic ecosystem AND functional linkages	1	0	0	1	2	2	2	1	1	1	2
ecosystem AND natural AND technical	13	12	12	9	21	17	22	27	21	31	25
aquatic ecosystem AND natural AND technical	1	0	1	0	3	2	3	3	2	1	2

Number of publications (choice for search space "article or review") with "Search term" in title, abstract or key words:

Base Year = 1999 (alternatively 1998)

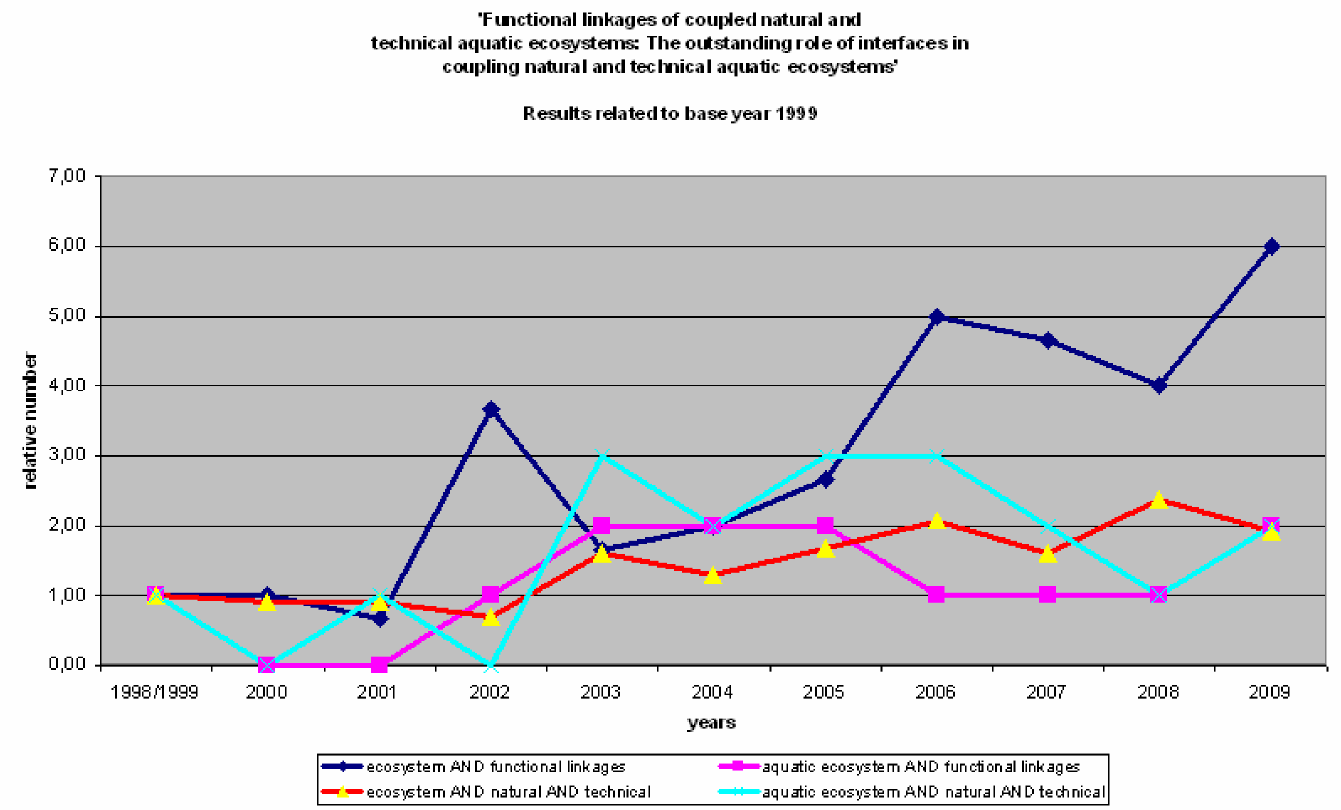


Relative Numbers

Results related to base year 1999

	1998/19!	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
ecosystem AND functional linkages	1,00	1,00	0,67	3,67	1,67	2,00	2,67	5,00	4,67	4,00	6,00
aquatic ecosystem AND functional linkages	1,00	0,00	0,00	1,00	2,00	2,00	2,00	1,00	1,00	1,00	2,00
ecosystem AND natural AND technical	1,00	0,92	0,92	0,69	1,62	1,31	1,69	2,08	1,62	2,38	1,92
aquatic ecosystem AND natural AND technical	1,00	0,00	1,00	0,00	3,00	2,00	3,00	3,00	2,00	1,00	2,00

Base Year = 1999 (alternatively 1998)



Division of articles and reviews into disciplines

ecosystem AND functional linkages

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	3	2	2	11	5	6	8	15	14	12	18
Social Sciences	0	1	0	0	1	1	1	0	1	2	3
Engineering Sciences	0	1	0	0	0	1	0	0	0	1	1

aquatic ecosystem AND functional linkages

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	1	0	0	1	2	2	2	1	1	1	2
Social Sciences	0	0	0	0	0	0	0	0	0	1	1
Engineering Sciences	0	0	0	0	0	0	0	0	0	0	0

ecosystem AND natural AND technical

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	11	11	11	9	20	17	18	20	19	29	24
Social Sciences	2	4	2	3	6	4	4	5	5	4	4
Engineering Sciences	1	3	1	4	4	2	1	6	2	2	4

aquatic ecosystem AND natural AND technical

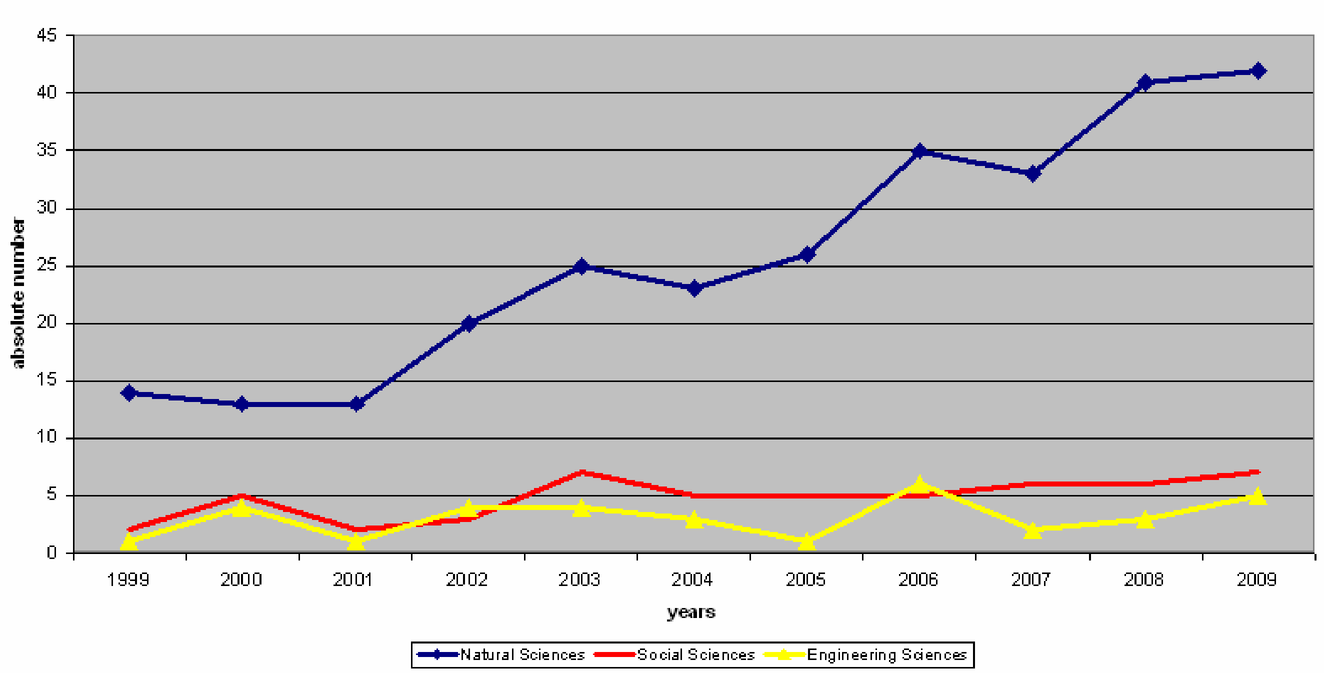
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	1	0	0	0	3	2	3	3	2	1	2
Social Sciences	0	0	0	0	0	0	0	0	0	0	1
Engineering Sciences	0	0	1	0	0	0	0	0	0	0	0

Search terr

Natural Sci
Social Scie
Engineerin

'Functional linkages of coupled natural and technical aquatic ecosystems: The outstanding role of interfaces in coupling natural and technical aquatic ecosystems'

Subject Areas: absolute results



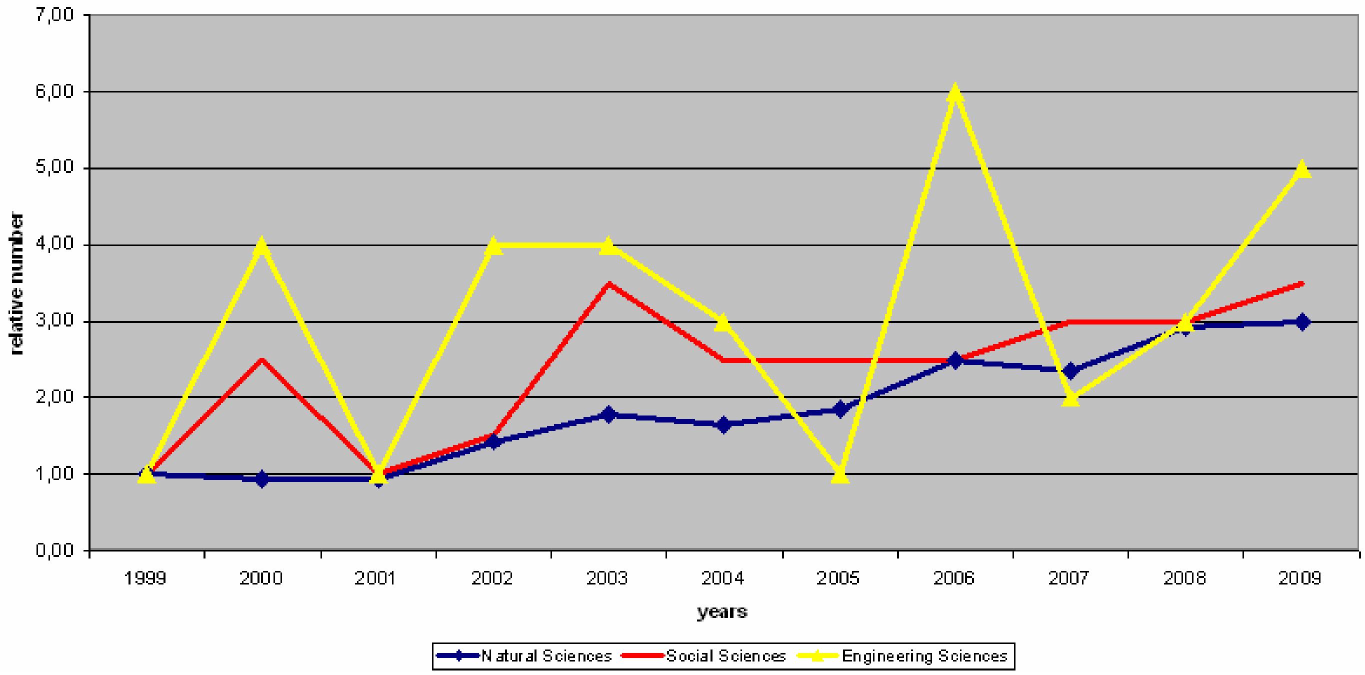
Results related to base year 1999 (Search term: ecosystem OR aquatic ecosystem AND functional linkages OR (natrual AND technical)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	1,00	0,93	0,93	1,43	1,79	1,64	1,86	2,50	2,36	2,93	3,00
Social Sciences	1,00	2,50	1,00	1,50	3,50	2,50	2,50	2,50	3,00	3,00	3,50
Engineering Sciences	1,00	4,00	1,00	4,00	4,00	3,00	1,00	6,00	2,00	3,00	5,00

Base Year = 1999

'Functional linkages of coupled natural and technical aquatic ecosystems: The outstanding role of interfaces in coupling natural and technical aquatic ecosystems'

Subject Areas: Results related to base year 1999

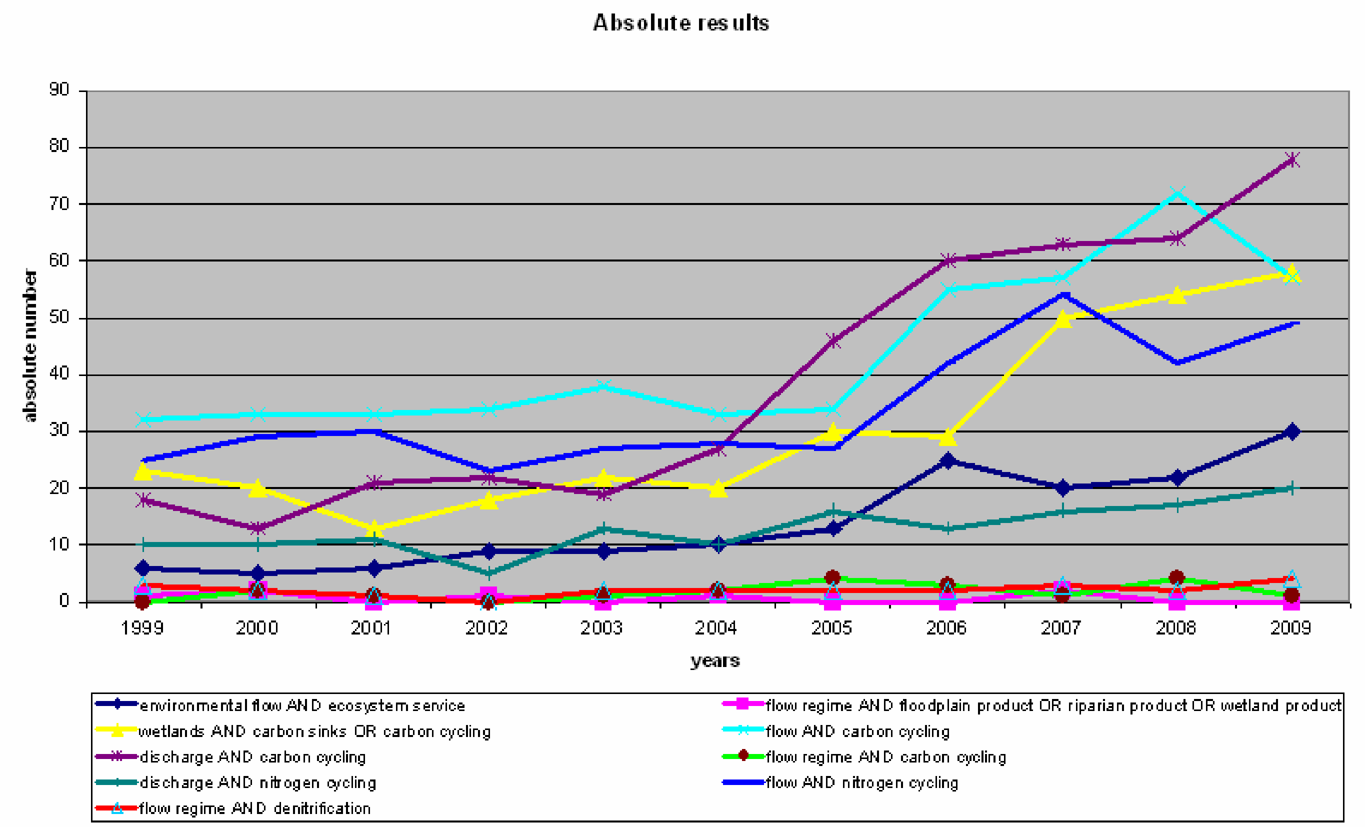


Application Area 2: Process based understanding of hydrological-ecological linkages and feedbacks, e.g. focus on carbon cycling, nitrogen cycling

Absolute Numbers

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
environmental flow AND ecosystem service	6	5	6	9	9	10	13	25	20	22	30
flow regime AND floodplain product OR riparian product OR wetland product	1	2	0	1	0	1	0	0	2	0	0
wetlands AND carbon sinks OR carbon cycling	23	20	13	18	22	20	30	29	50	54	58
flow AND carbon cycling	32	33	33	34	38	33	34	55	57	72	57
discharge AND carbon cycling	18	13	21	22	19	27	46	60	63	64	78
flow regime AND carbon cycling	1*	2	1	0	1	2	4	3	1	4	1
discharge AND nitrogen cycling	10	10	11	5	13	10	16	13	16	17	20
flow AND nitrogen cycling	25	29	30	23	27	28	27	42	54	42	49
flow regime AND denitrification	3	2	1	0	2	2	2	2	3	2	4

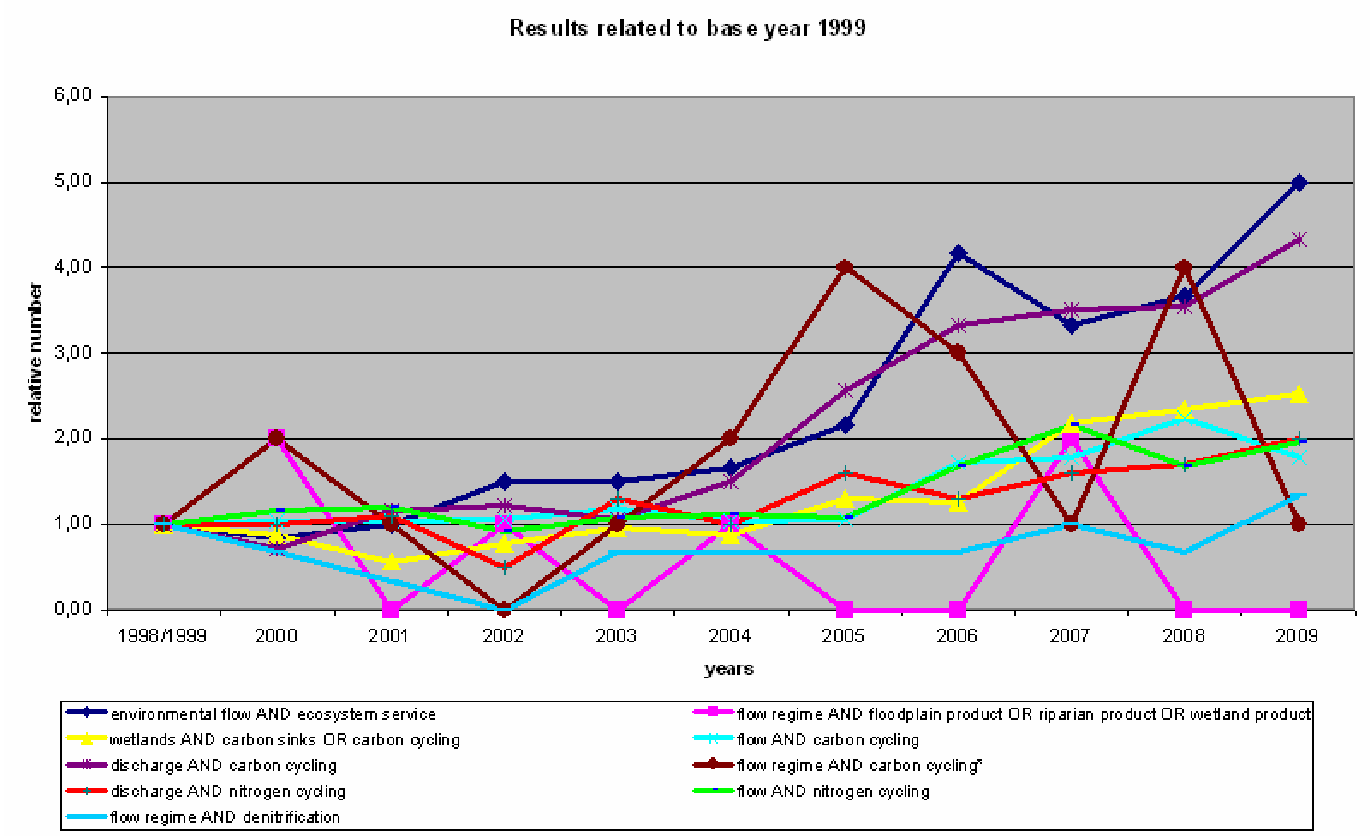
Number of publications (choice for search space "article or review") with "Search term" in title, abstract or key words;
Base Year = 1999 (* alternatively 1998)



Relative Numbers

Results related to base year 1999 (*alternatively 1998)

	1998/199	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
environmental flow AND ecosystem service	1,00	0,83	1,00	1,50	1,50	1,67	2,17	4,17	3,33	3,67	5,00
flow regime AND floodplain product OR riparian product OR wetland product	1,00	2,00	0,00	1,00	0,00	1,00	0,00	0,00	2,00	0,00	0,00
wetlands AND carbon sinks OR carbon cycling	1,00	0,87	0,57	0,78	0,96	0,87	1,30	1,26	2,17	2,35	2,52
flow AND carbon cycling	1,00	1,03	1,03	1,06	1,19	1,03	1,06	1,72	1,78	2,25	1,78
discharge AND carbon cycling	1,00	0,72	1,17	1,22	1,06	1,50	2,56	3,33	3,50	3,56	4,33
flow regime AND carbon cycling*	1,00	2,00	1,00	0,00	1,00	2,00	4,00	3,00	1,00	4,00	1,00
discharge AND nitrogen cycling	1,00	1,00	1,10	0,50	1,30	1,00	1,60	1,30	1,60	1,70	2,00
flow AND nitrogen cycling	1,00	1,16	1,20	0,92	1,08	1,12	1,08	1,68	2,16	1,68	1,96
flow regime AND denitrification	1,00	0,67	0,33	0,00	0,67	0,67	0,67	0,67	1,00	0,67	1,33



Division of articles and reviews into disciplines

environmental flow AND ecosystem service

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	6	3	6	9	9	10	13	25	20	21	29
Social Sciences	1	2	2	2	3	3	2	4	6	3	6
Engineering Sciences	0	2	0	1	1	2	0	4	1	4	5

flow regime AND floodplain product OR riparian product OR wetland product

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	1	2	0	1	0	1	0	0	2	0	0
Social Sciences	0	0	0	0	0	0	0	0	0	0	0
Engineering Sciences	1	0	0	0	0	0	0	0	0	0	0

wetlands AND carbon sinks OR carbon cycling

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	23	20	13	18	22	20	30	29	50	53	58
Social Sciences	0	1	1	0	0	0	2	2	3	2	7
Engineering Sciences	0	1	0	0	0	0	2	3	3	1	1

flow AND carbon cycling

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	29	32	29	32	37	31	34	51	53	67	57
Social Sciences	6	3	5	1	3	2	5	2	5	6	5
Engineering Sciences	7	1	3	3	3	6	5	9	5	15	5

discharge AND carbon cycling

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	18	13	18	20	17	21	35	49	55	53	75
Social Sciences	0	0	0	0	0	0	1	0	1	0	0
Engineering Sciences	10	7	16	16	11	22	27	43	46	46	57

flow regime AND carbon cycling

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	0	2	1	0	1	2	4	3	1	4	1
Social Sciences	0	0	0	0	0	0	0	0	0	1	0
Engineering Sciences	0	0	0	0	0	0	0	0	0	1	0

discharge AND nitrogen cycling

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	10	10	10	5	12	9	15	10	15	15	20
Social Sciences	0	0	0	0	0	0	0	0	0	0	0
Engineering Sciences	1	0	2	0	1	3	3	5	3	4	4

flow AND nitrogen cycling

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	24	28	29	21	26	25	25	40	54	42	49
Social Sciences	1	1	1	1	2	1	2	0	0	2	4
Engineering Sciences	3	1	3	2	1	5	4	4	4	3	5

flow regime AND denitrification

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	3	2	1	0	2	2	2	2	3	2	4
Social Sciences	0	0	0	0	0	0	0	0	0	0	0
Engineering Sciences	0	0	0	0	0	0	0	1	0	0	0

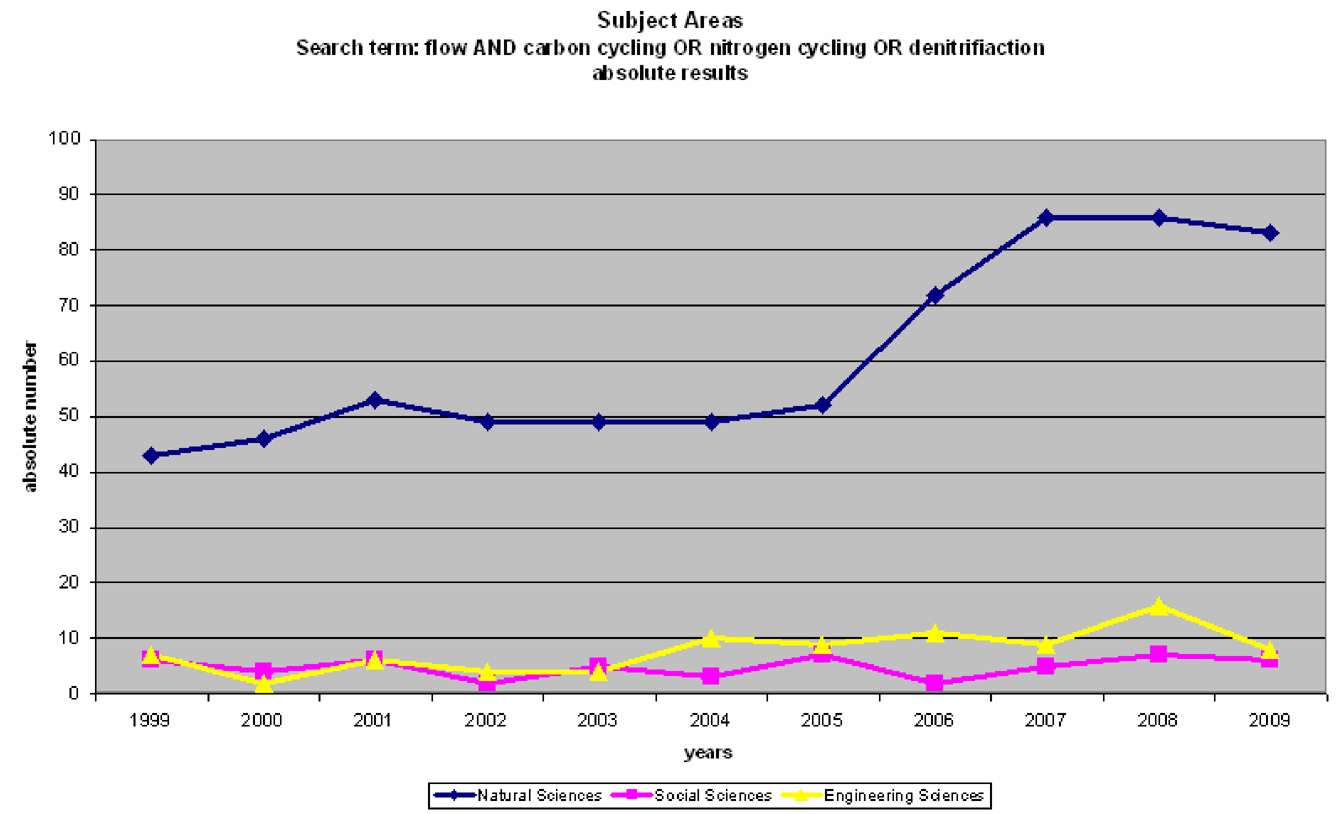
Search term: flow AND carbon cycling OR nitrogen cycling OR denitrifiaction

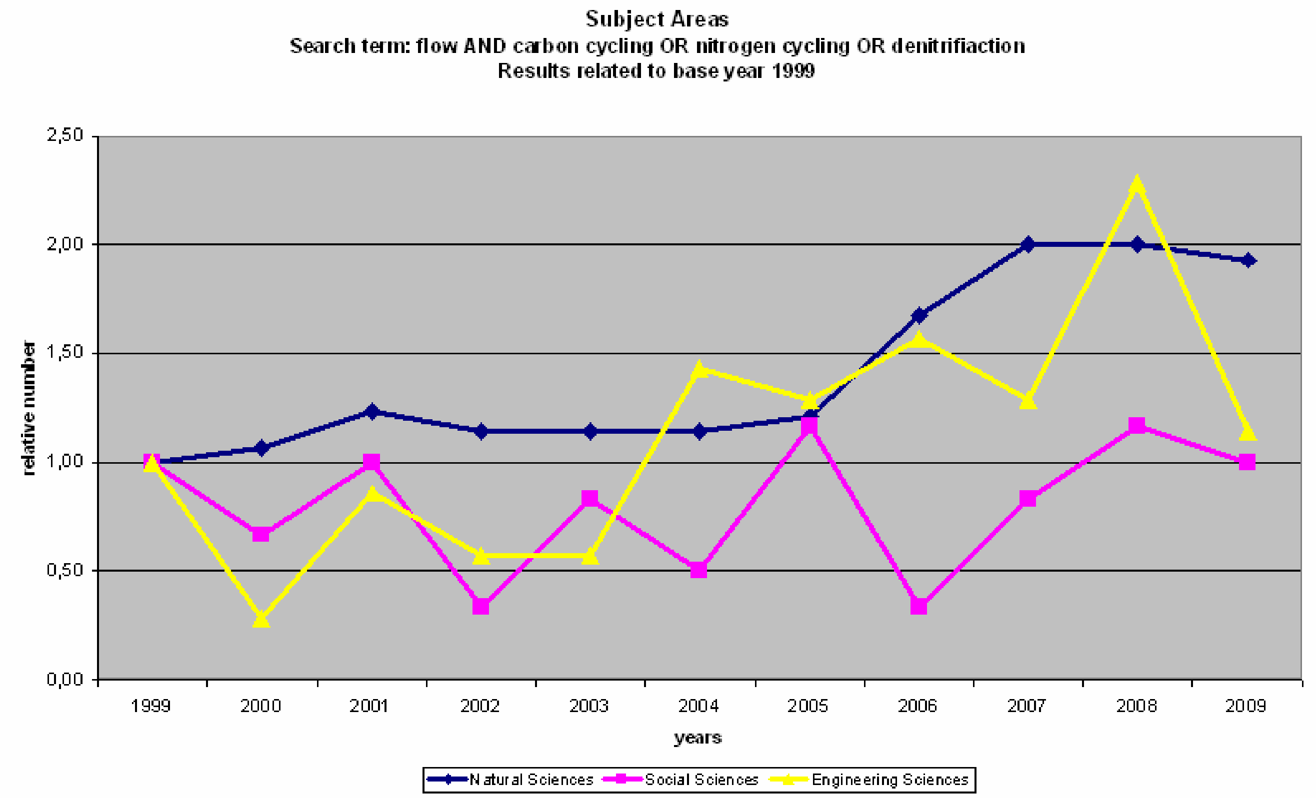
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	43	46	53	49	49	49	52	72	86	86	83
Social Sciences	6	4	6	2	5	3	7	2	5	7	6
Engineering Sciences	7	2	6	4	4	10	9	11	9	16	8

Results related to base year 1999 (Search term: flow AND carbon cycling OR nitrogen cycling OR denitrifiaction)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	1,00	1,07	1,23	1,14	1,14	1,14	1,21	1,67	2,00	2,00	1,93
Social Sciences	1,00	0,67	1,00	0,33	0,83	0,50	1,17	0,33	0,83	1,17	1,00
Engineering Sciences	1,00	0,29	0,86	0,57	0,57	1,43	1,29	1,57	1,29	2,29	1,14

Base Year = 1999



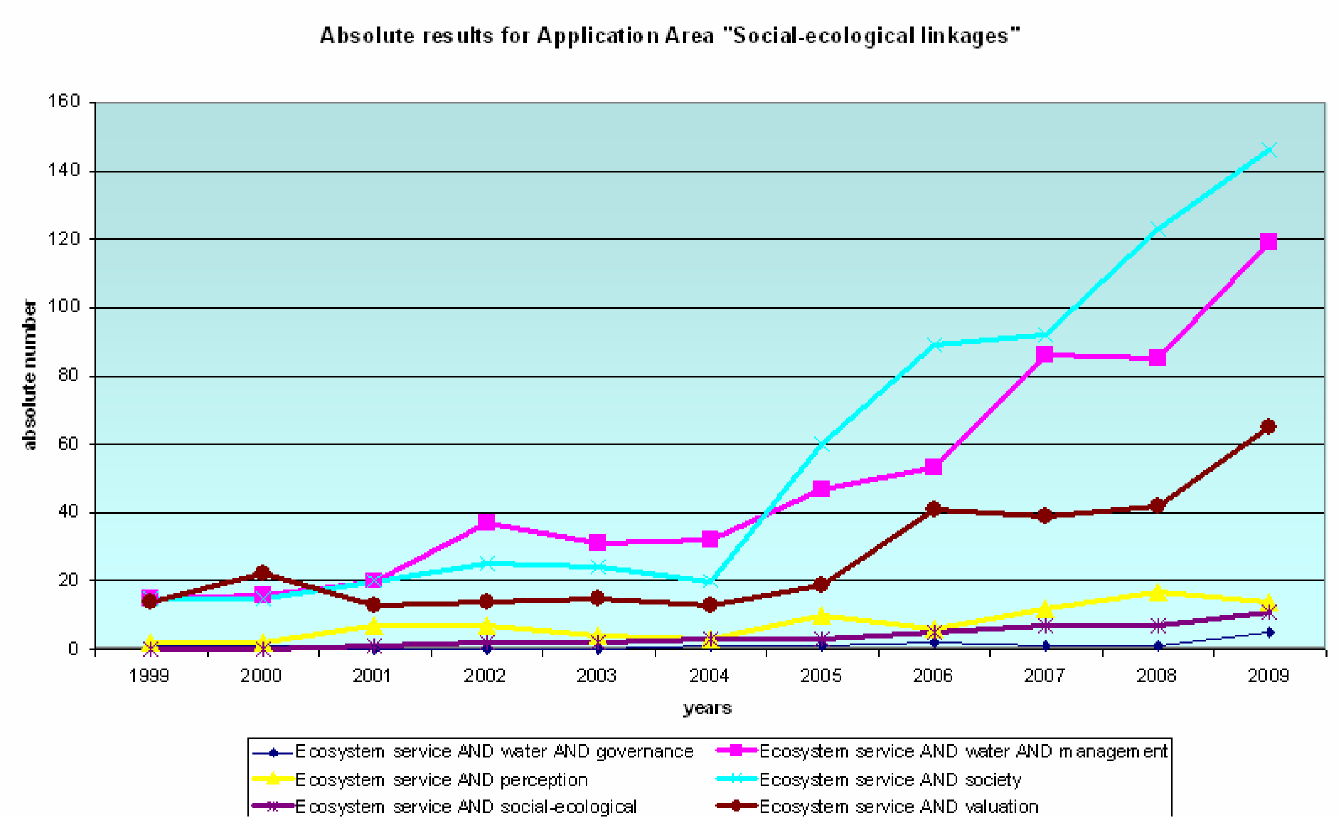


Application Area 3: Process based understanding of social-ecological linkages and feedbacks: how do societies depend on ecosystem services?

<u>Absolute Numbers</u>

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Ecosystem service AND water AND governance	1	1	0	0	0	1	1	2	1	1	5
Ecosystem service AND water AND management	15	16	20	37	31	32	47	53	86	85	119
Ecosystem service AND perception	2	2	7	7	4	3	10	6	12	17	14
Ecosystem service AND society	15	15	20	25	24	20	60	89	92	123	146
Ecosystem service AND social-ecological	0	0	1	2	2	3	3	5	7	7	11
Ecosystem service AND valuation	14	22	13	14	15	13	19	41	39	42	65

Number of publications (choice for search space "article or review") with "Search term" in title, abstract or key words:

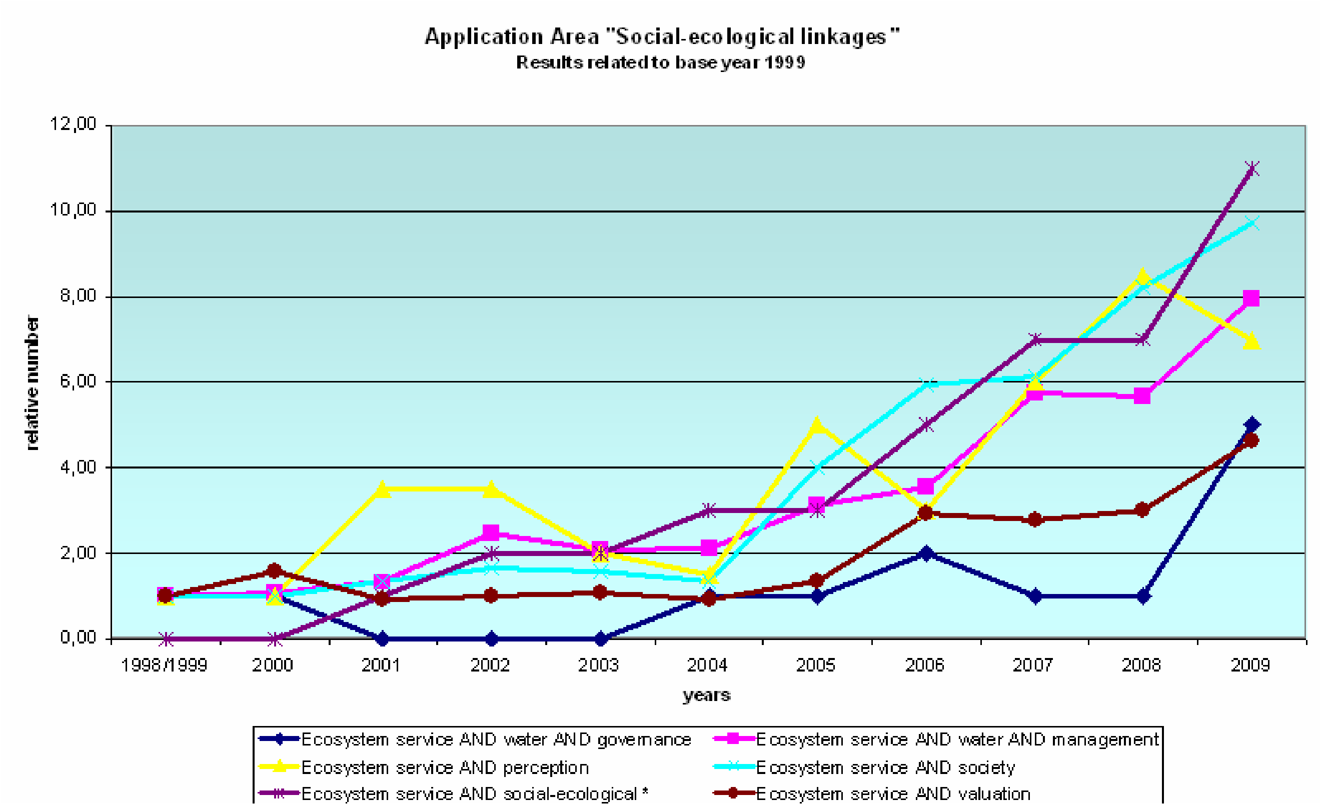


Relative Numbers

Results related to base year 1999

	1998/199	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Ecosystem service AND water AND governance	1,00	1,00	0,00	0,00	0,00	1,00	1,00	2,00	1,00	1,00	5,00
Ecosystem service AND water AND management	1,00	1,07	1,33	2,47	2,07	2,13	3,13	3,53	5,73	5,67	7,93
Ecosystem service AND perception	1,00	1,00	3,50	3,50	2,00	1,50	5,00	3,00	6,00	8,50	7,00
Ecosystem service AND society	1,00	1,00	1,33	1,67	1,60	1,33	4,00	5,93	6,13	8,20	9,73
Ecosystem service AND social-ecological *	0,00	0,00	1,00	2,00	2,00	3,00	3,00	5,00	7,00	7,00	11,00
Ecosystem service AND valuation	1,00	1,57	0,93	1,00	1,07	0,93	1,36	2,93	2,79	3,00	4,64

Base Year = 1999 (*=alternatively 2001)



Division of articles and reviews into disciplines

Ecosystem service AND water AND governance

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	1	1	0	0	0	1	0	1	0	1	5
Social Sciences	1	0	0	0	0	1	1	1	1	0	3
Engineering Sciences	0	0	0	0	0	0	0	0	0	0	1

Ecosystem service AND water AND management

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	14	15	20	35	30	30	42	50	83	81	114
Social Sciences	3	3	4	11	6	5	14	8	16	17	32
Engineering Sciences	0	2	1	4	2	3	4	9	7	12	12

Ecosystem service AND perception

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	2	2	6	6	4	3	10	6	11	16	11
Social Sciences	0	2	3	2	1	0	2	1	2	6	6
Engineering Sciences	0	0	1	1	1	0	0	0	1	0	2

Ecosystem service AND society

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	15	14	18	22	23	17	52	85	88	114	138
Social Sciences	4	4	7	10	4	3	9	12	16	13	26
Engineering Sciences	0	5	2	5	2	2	6	6	7	8	9

Ecosystem service AND social-ecological

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	0	0	0	2	2	3	3	5	7	7	11
Social Sciences	0	0	1	0	0	0	0	1	0	1	2
Engineering Sciences	0	0	0	0	1	0	0	1	0	1	1

Ecosystem service AND valuation

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	13	21	13	14	15	13	19	41	36	41	61
Social Sciences	6	6	5	13	8	4	4	20	18	18	24
Engineering Sciences	0	2	0	1	0	1	1	1	3	6	10

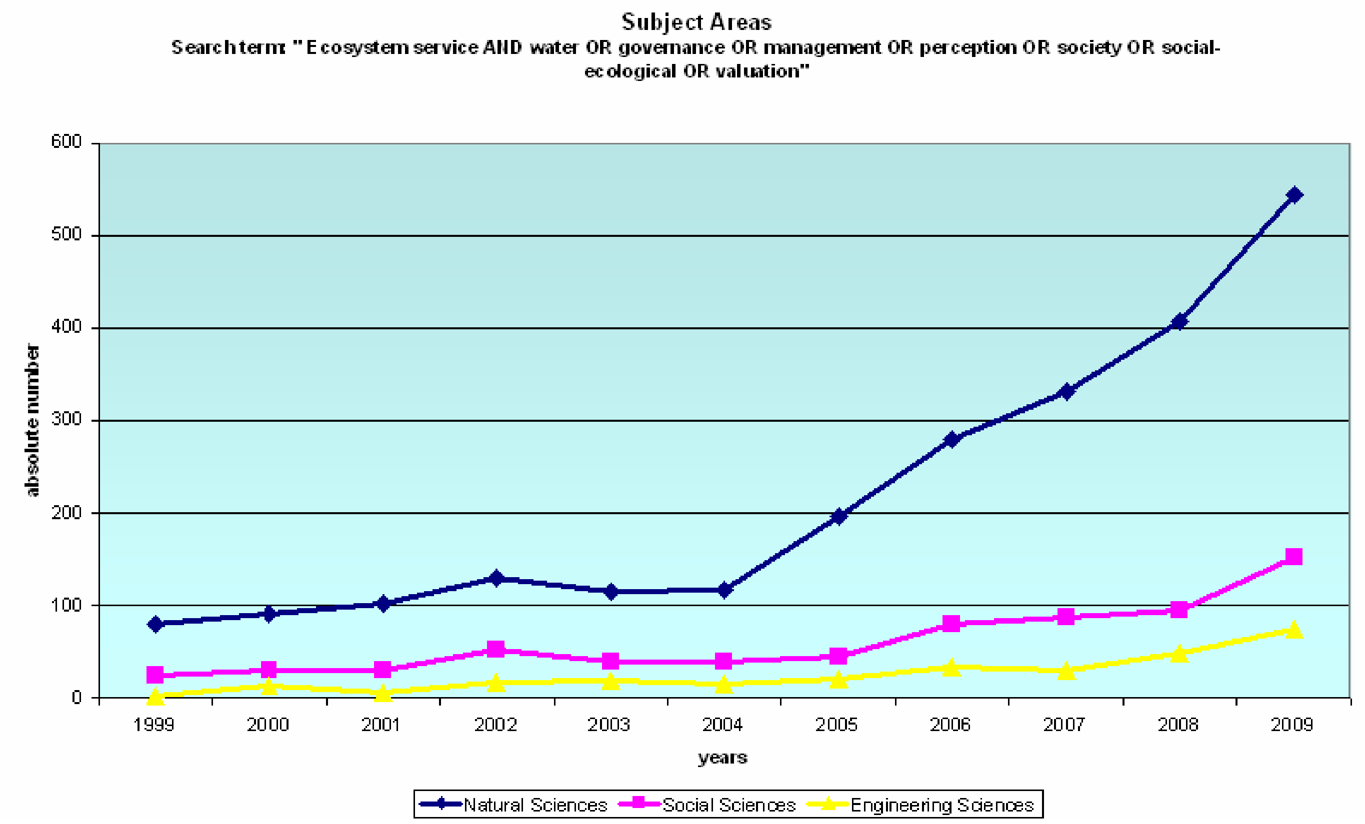
Search term: Ecosystem service AND water OR governance OR management
OR perception OR society OR social-ecological OR valuation

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	81	91	102	130	116	117	197	279	331	408	543
Social Sciences	25	30	31	53	40	39	45	80	88	95	152
Engineering Sciences	3	13	7	18	20	16	21	34	31	49	75

Results related to base year 1999 (Search term: Ecosystem service AND water OR governance OR management OR perception OR society OR social-ecological OR valuation)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	1,00	1,12	1,26	1,60	1,43	1,44	2,43	3,44	4,09	5,04	6,70
Social Sciences	1,00	1,20	1,24	2,12	1,60	1,56	1,80	3,20	3,52	3,80	6,08
Engineering Sciences	1,00	4,33	2,33	6,00	6,67	5,33	7,00	11,33	10,33	16,33	25,00

Base Year = 1999


Subject Areas
Search term: " Ecosystem service AND water OR governance OR management OR perception OR society OR social-ecological OR valuation"
600
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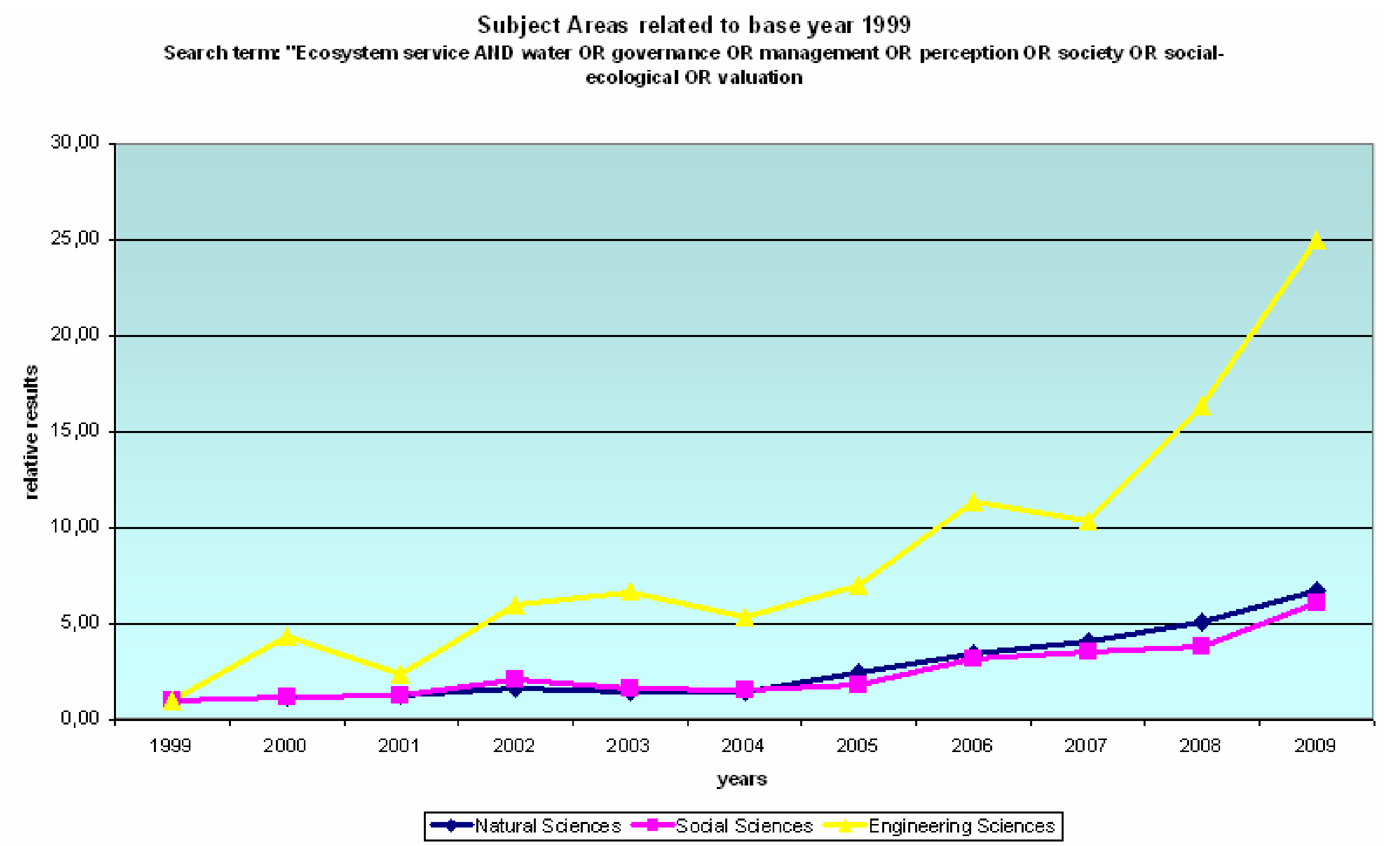
Engineering Sciences


Subject Areas related to base year 1999
Search term: "Ecosystem service AND water OR governance OR management OR perception OR society OR social-ecological OR valuation
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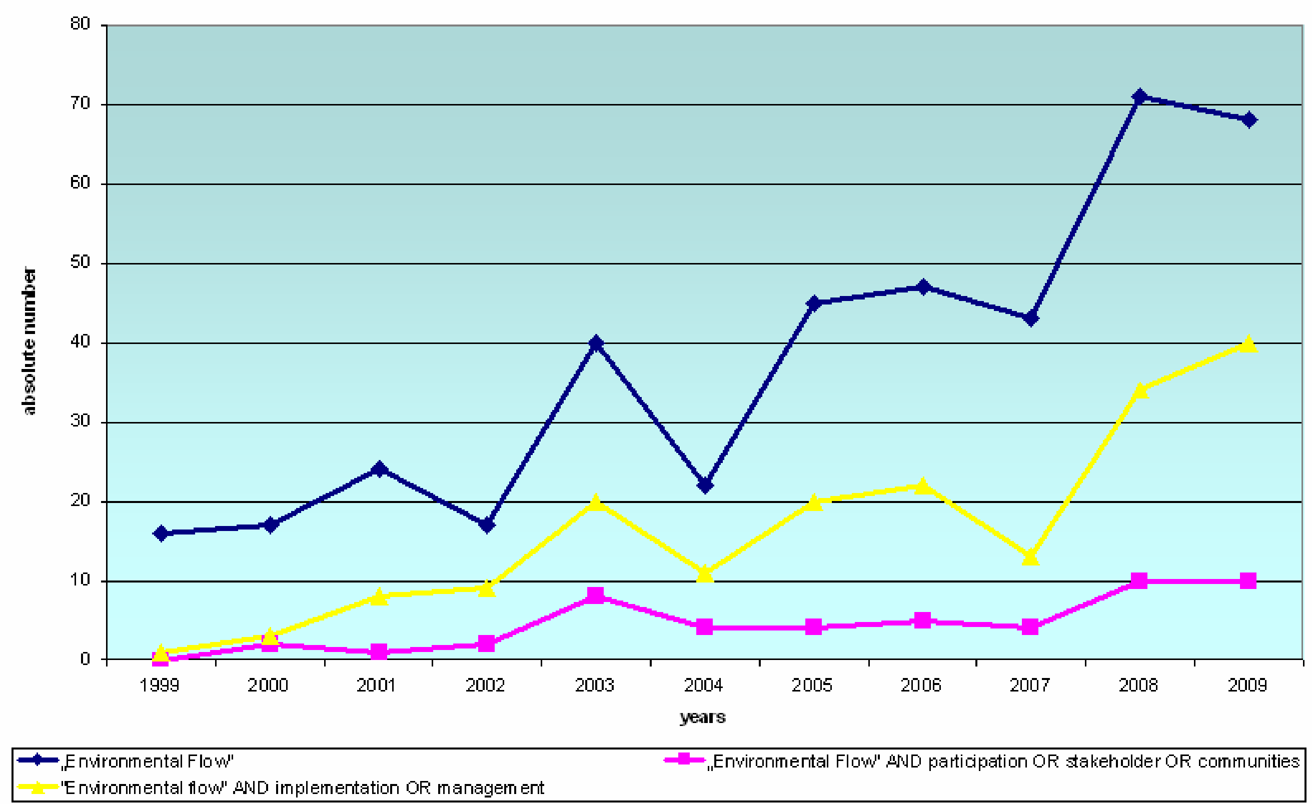
years
Natural Sciences
Social Sciences
Engineering Sciences

Application Area 4: Management tools for implementation of environmental flows (focussing on stakeholder involvement)

Absolute Numbers

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
„Environmental Flow“	16	17	24	17	40	22	45	47	43	71	68
„Environmental Flow“ AND participation OR stakeholder OR communities	1 *	2	1	2	8	4	4	5	4	10	10
"Environmental flow" AND implementation OR management	1	3	8	9	20	11	20	22	13	34	40
Relate to base year = Base year Factor											

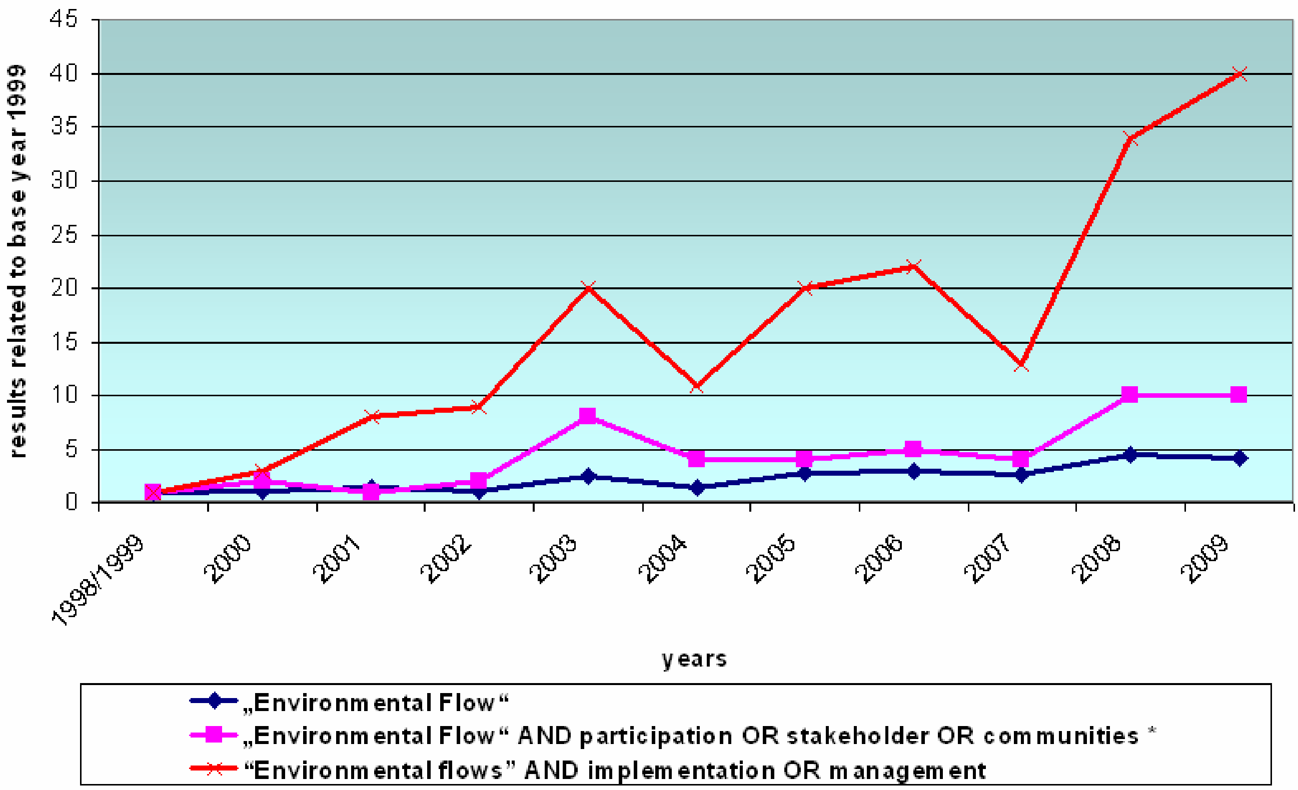
Number of publications (choice for search space "article or review") with "Search term" in title, abstract or key words:
Base Year = 1999 (*= alternatively 1998)



Relative Numbers

	1998/19	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
„Environmental Flow“	1,00	1,06	1,50	1,06	2,50	1,38	2,81	2,94	2,69	4,44	4,25
„Environmental Flow“ AND participation OR stakeholder OR communities *	1,00	2,00	1,00	2,00	8,00	4,00	4,00	5,00	4,00	10,00	10,00
“Environmental flows” AND implementation OR management	1,00	3,00	8,00	9,00	20,00	11,00	20,00	22,00	13,00	34,00	40,00

Base Year = 1999 (*= alternatively 1998)



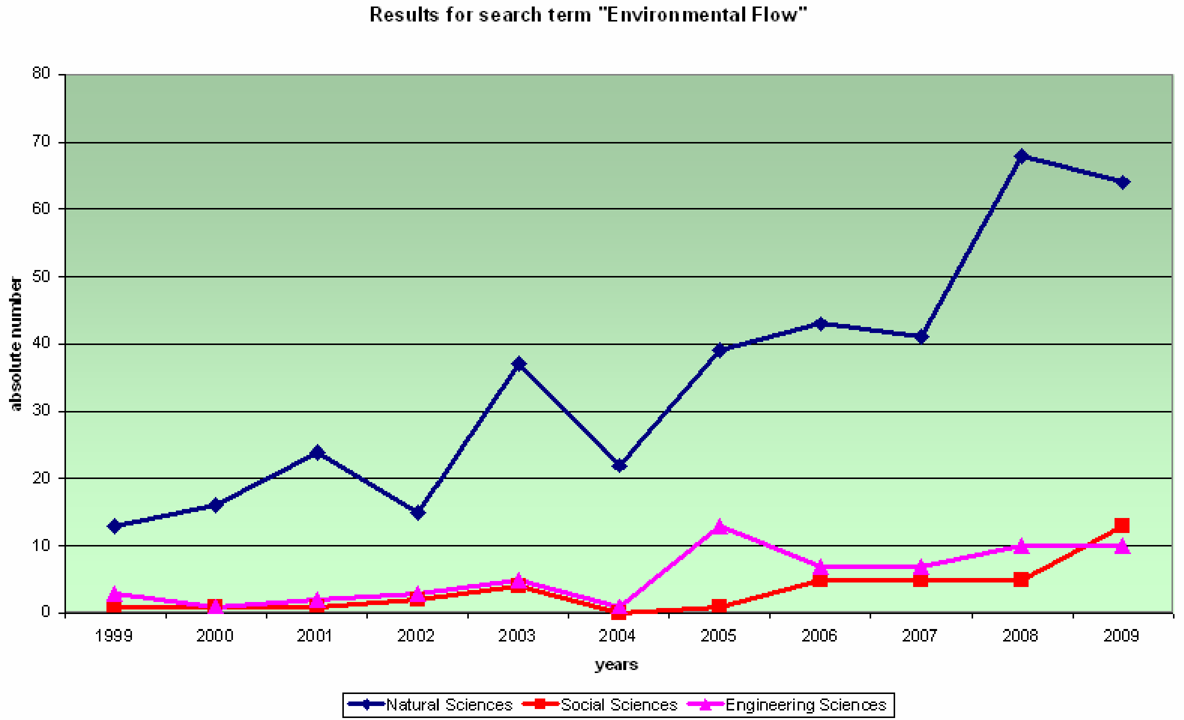
Division of articles and reviews into disciplines

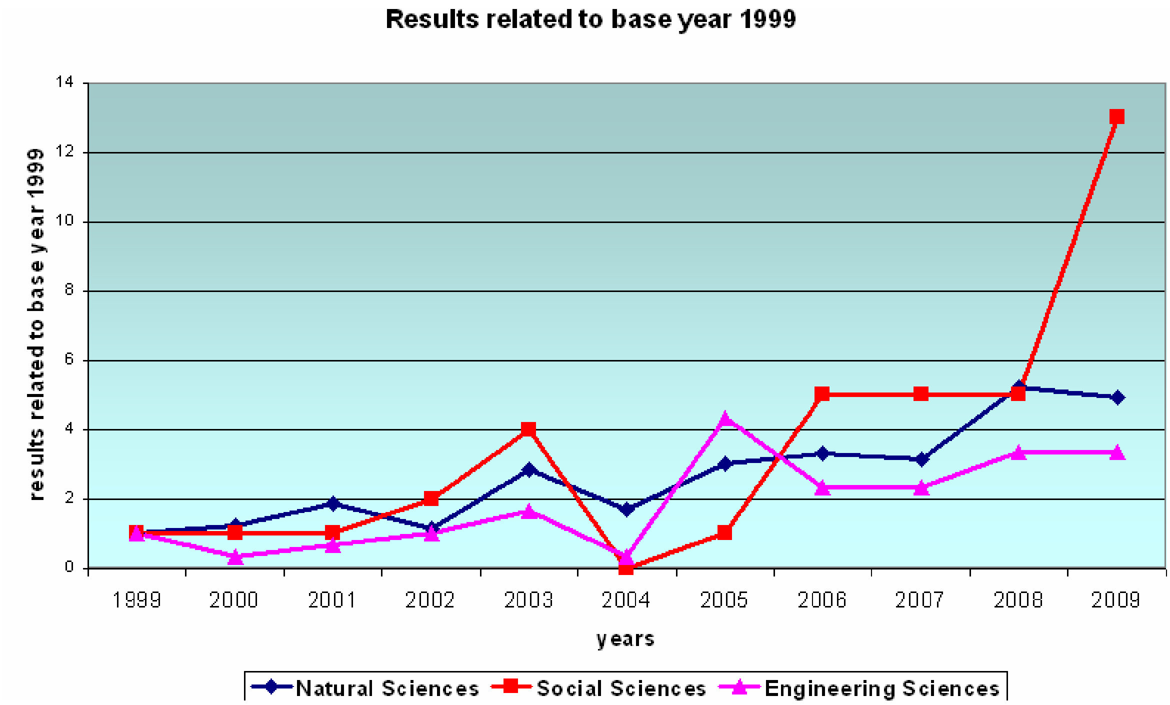
Search term "Environmental Flow"

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natural Sciences	13	16	24	15	37	22	39	43	41	68	64
Social Sciences	1	1	1	2	4	0	1	5	5	5	13
Engineering Sciences	3	1	2	3	5	1	13	7	7	10	10

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Natura										5,23	4,92
Social :										5,00	13,00
Engine										3,33	3,33

Base Ye




Results related to base year 1999
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Natural Sciences
Social Sciences
Engineering Sciences

Manipulating flow and water bodies for managing ecosystem services[1]

Johannes Halbe, Birgitta Malm-Renöfält, Gunnar Nützmann, Carolin Rettig

1. Background

The theme cluster 'Manipulating flow and water bodies for managing ecosystem services' was identified to be one of the key themes during an international expert workshop on 'Future trends and research needs in water management' held in Osnabrück in February 2010. Based on initial literature reviews, originally, the theme cluster was titled 'Environmental flows, water related ecosystem services and trade-offs between human and environmental water needs' pointing out scientific gaps related to: quantitative knowledge about the status and importance of fresh water ecosystems including ground water, implementation difficulties of environmental flow assessments, valuation of ecosystem services, the role of governance regimes, as well as the adaptation capacity of social-ecological systems. This served as a starting point for discussions at the aforementioned workshop and was further refined by a panel of experts. As a result recommendations for future research were made. According to the discussion outcomes the key challenges of future research related to environmental flows are:

1. Functional linkages of natural and technical aquatic ecosystems
2. Process based understanding of hydrological-ecological linkages and feedbacks
3. Process based understanding of social-ecological linkages and feedbacks
4. Management tools for implementation of environmental flows

This expert judgement on future research needs and the relevance of this Application Area was elaborated upon by further assessments based on thorough literature reviews, which are presented below.

2. Introduction: Relevance of the theme cluster

The management of ecosystem services entails many challenges and requires integrated approaches that take into consideration both the ecological as well as the human dimensions to be able to address the multitude of underlying linkages and dynamics affecting ecosystem health and sustainable management.

The recognition of flow as a key driver of aquatic ecosystems has led to the development of the environmental flows concept. Environmental flows (EF's) describe the quantity, quality and timing of water flows required to sustain freshwater ecosystems in managed rivers (Dyson *et al*. 2003). Other concepts exist, such as minimum, or in stream flow. However such flow concepts lack a holistic view of the ecosystem and the services it provides, focusing on only one or a few aspects. The need to provide for EF's is well recognized among freshwater scientists. In 2007, the Brisbane Declaration on Environmental Flows was endorsed by more than 800 delegates from 57 countries (Brisbane declaration, 2007). The declaration announces an official pledge to work together to protect and restore the world's rivers and lakes through incorporating EF's in water management strategies. Environmental flows are defined in the Brisbane Declaration as the "quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihood and well-being that depend on these ecosystems" (Brisbane Declaration 2007). This definition highlights the importance of environmental flows for the preservation of ecosystem functions and services.

[1] This Theme Cluster is based on the full contributions on the individual application areas by the four authors. These are included on the CD accompanying this final report.

Water plays a key role in the landscape system by being central for the survival for all living organisms (Falkenmark and Mikulski 1994). Changes in water bodies and ecosystems are however not undesirable as such. In fact, changes in an ecosystem are often inevitable if not mandatory for its overall integrity (Holling et al. 2002; Walker et al. 2004). Ecosystems have adapted to site-specific water availability in terms of quantity, variability, and quality through a long-term evolutionary process. Fauna and flora heavily depend on the natural flow regime of rivers (see Walker et al. 1995; Power et al. 1995; Poff et al. 1997; Bunn and Arthington 2002; Lytle and Poff 2004). Thus, the alteration of the key variable 'streamflow' induces profound changes in the ecosystem (Bunn and Arthington 2002; Poff and Zimmerman 2010). The ecological-hydrological linkages and the management tools used for implementing the environmental flows concept are further explained in chapters 3.2 and 3.4.

The effects of alterations must be taken into consideration when managing ecosystems. Humans have a long history of making use of aquatic ecosystems and have altered these accordingly, having created technical aquatic ecosystems. These are closely interlinked with the natural ecosystems, which is starting to be recognized: recent developments in environmental legislation in Europe, such as the EU Water Framework Directive require a more integrated approach to the management of hydrological catchments (Solimini et al. 2009). Similar approaches are advocated elsewhere (e.g. Winter et al. 2003). Holistic assessment and management of catchments therefore require a good understanding of interfaces between environmental compartments, especially in coupled natural-urban systems. The linkages between human and technical aquatic ecosystems are elaborated upon in chapter 3.1.

The 'ecosystem services' and 'ecosystem functions' concepts address the relation of physical or ecological systems and human values. Ecosystem functions (e.g. soil rentention) are the ecosystem processes that are used and valued by people, and thereby become ecosystem services (e.g. prevention of damage from erosion) (cf. de Groot 2006; Termorshuizen and Opdam 2009). The Millennium Ecosystem Assessment (MEA, 2005) placed ecosystem services into the categories *provisioning, regulating, cultural, and supporting*. Provisioning services are most clearly recognizable services and provide direct products people can use such as clean drinking water, or fertile land for agriculture and grazing. In respect to freshwater ecosystems, inland fisheries in developing countries may provide the only source of animal protein for rural people (Welcomme et al. 2006). Regulating services like natural purification in wetlands and river ecosystems are often less obvious. The natural flow regime of rivers supports a variety of regulating ecosystem services, such as erosion, pollution, and flood and pest control (Poff et al. 1997). Recreational, spiritual, aesthetic services are examples for cultural services of wetlands. Water in general, and rivers in particular have a special value in the culture and spiritual traditions of indigenous peoples (Craig 2007). Supporting services are necessary for the provision of all other ecosystem services. Their impacts on people are indirect or occur at longer time frames compared to other types of services. Examples are soil formation, nutrient cycling or climate regulation among others (MEA, 2005). Hydrologic alterations also have an impact on these supporting services like nutrient cycling and biodiversity (Pringle 1997, Richter et al. 1998).

However, when dealing with ecosystem functions and services, it must be borne in mind that other classifications of ecosystem services exist. Wallace (2007) criticizes the MEA categories as being "not a coherent set of services at the same level that can be explored and traded off in a decision system" (2007, p. 238). For instance, food production (provisioning service) is an end of an ecosystem management process, while pollination (regulating service) is a means of service delivery. He also considers 'ecosystem function' as an ambiguous concept that is not required for the analysis of ecosystem services. Thus, Wallace (2007) proposes an alternative classification scheme that differentiates between ecosystem services, processes and structure.

Independent of how ecosystem services are categorized the reliance of humans on ecosystem services is widely agreed upon. This is most evident when looking at benefits that are of a material nature, for example, drinking water, fish and sea-food, as well as water for agricultural and industrial purposes. Albeit less visible the non-material services, such as climate regulation, pollination or nutrient cycling, are just as important for human well-being. Le Maitre et al. (2005) point out how ecologists have stressed human dependencies on ecosystem services for decades. The nature of the dependencies and other social-ecological linkages are dealt with in more detail in chapter 3.3

3. Application Areas

The following sections present elaborations on the individual Application Areas, which will form the basis for an overall synthesis. Some connections between different Application Areas will already become apparent or are explicitly referred to within the coming sections. These are important in relation to identifying future research needs and, more specifically, making recommendations for future research programmes (see chapter 4.5).

3.1 Application Area 1:

Functional linkages of coupled natural and technical aquatic ecosystems (rural-urban linkages)

Introduction

There are numerous natural and technical interfaces in rural and urban water systems which link different compartments of the water cycle (e.g. surface water–groundwater, water–atmosphere, water–soils) or which link natural and technical urban water compartments (e.g. wastewater–gas in sewer systems and wastewater treatment plants, surface water–groundwater at bank filtration sites). Fluxes across interfaces are the exchange of water, dissolved substances, gases and energy between the different compartments. Interfaces are generally characterized by steep physical and biogeochemical gradients, disproportionately high numbers of micro-organisms, intense reaction rates and non-linear interactions as well as feedback mechanisms between the different systems. The interfaces themselves are heterogeneous (i. e. there are hot spots), process intensities fluctuate (i. e. hot moments occur) and interface structure might be dynamic if biota is involved or the system is disturbed by external impacts. All these circumstances make fluxes across interfaces highly complex and they are much less understood compared to processes in single compartments. Therefore, the state of the art in the field of fluxes across interface is characterized by considerable knowledge gaps.

Additionally, aquatic sediments act as dynamic sinks and sources in urban matter fluxes. Climate change, technical systems and management measures can change the function of interfaces in aquatic systems. Anaerobic processes in sediments should be investigated with focus on production of greenhouse gases and the remobilization of nutrients and harmful substances. Water quality might be altered when water transits highly reactive interfaces. For example, soil surfaces are an important interface linking atmosphere and hydrosphere. However, urban soils are drastically disturbed. Management of urban lawns and recreational lands are energy-intensive with a large input of fertilizers, pesticides and irrigation water. The free water surface is another interface linking atmosphere and hydrosphere. It acts as – partially bi-directional – exchange area of water (vapour), energy, (dissolved) gases (air, greenhouse gases) or nano-particles. The expected temperature increase due to anthropogenic climate change will affect the fluxes across interfaces via water surfaces thus influencing the urban micro-climate as well as lake dynamics, for example, due to shifts in ice cover periods.

There is a strong need to study these fluxes, the effects on the linked natural-urban water cycle and the processes which control the fluxes.

All these interfaces were previously boundaries of environmental management units, but are now recognised to be important areas for cycling of energy, nutrients and organic compounds (McClain et al. 2003), and exert significant control over catchment-wide pollutant transfer (Smith et al. 2009) and ecological health (Brunke and Gonser 1997). Four examples for coupled natural and technical ecosystems are: a) Bank filtration and artificial groundwater recharge systems, b) self-purification of rivers, c) Leaking sewer system, and d) the city-lake system. Explanations of these examples can be found in the full report (on CD).

The relevance of sub themes within this Application Area

A better understanding of the interface processes in coupled natural and technical freshwater ecosystems is the key for reliable assessments of the influence of changing boundary conditions (climate change, demography, emerging substances, and new technologies) on natural and urban water cycles and aquatic ecosystems. Ecosystem management (e.g. river and lake restoration) is necessary to maintain or restore biodiversity at a landscape scale. To be effective, conservation efforts should be based on a solid conceptual foundation and a holistic understanding of river and lake ecosystems. Such background knowledge is necessary to re-establish environmental gradients, to reconnect interactive pathways, and to reconstitute natural dynamics responsible for high levels of biodiversity. The challenge for the future lies in protecting the ecological integrity and biodiversity of aquatic systems in the face of increasing pressures on our freshwater resources. This will require integrating sound scientific principles with management perspectives that recognize floodplains, groundwater and catchments as integral components of surface waters. Management should be based on sustaining, rather than suppressing, environmental heterogeneity (Ward 1998). In that context, the following exiting research questions are to be addressed (e.g. Lovett et al. 2005):

- What are the physical and chemical boundary conditions that create ecosystem patterns and variations?
- What are the hydrologic processes that determine the variability in ecosystem structure and function?
- How do ecosystems interact with their aquatic and terrestrial environment?
- How does the water cycle interact with major biogeochemical cycles in ecosystems?

These topics which often have been investigated in a (more) isolated approach should be further developed in a strong interdisciplinary collaboration (water and environmental engineering, limnology, hydrogeology, chemistry, microbiology, environmental economics, social sciences and sustainability evaluations). Water issues need always a close connection and exchange between these fields of expertise (Royal Netherlands Academy of Arts and Science, 2005). Therefore, the following four sub themes are identified to be representative for national and international research activities, including methodological issues. In the centre stands the land–water interface, connecting terrestrial and aquatic ecosystems, coupling natural and technical systems and the functional linkages of such interfaces.

1) Connectivity of water and landscapes

To date, most studies on land-water interactions have focussed on the one-way interaction from land to water by examining the transport of terrestrial derived materials to aquatic ecosystems (Walsh et al. 2003). Although there has been much research on the effect of land use on streams (Meybeck 1998), lakes (Gächter & Wehrli 1998), and wetlands (Lehtinen et al. 1999) there are still significant knowledge gaps. Furthermore, to fully understand the complex interactions between aquatic and terrestrial ecosystems, aquatic ecosystems must not only be seen as receptor of human modification of the landscape, but also as potential drivers of modifications of the landscape (Riera et al. 2001). It may be important to put more emphasis into developing stricter zoning around lake shorelines that limit development or find ways to increase the amount of lakeside vegetation. In seepage lakes the close coupling of lakes and groundwater is often overlooked. It is quite difficult to quantify the amount and distribution of groundwater and substances entering lakes. Innovative measurement concepts are required for the groundwater–lake interface which is sometimes equivalent to a natural–technical interface (see also 'Introduction' of this chapter).

For streams, efforts have been put into place to preserve stream riparian and floodplain areas (see also Rockström et al. 2009). Riverine floodplains are highly complex, dynamic and diverse ecosystems, and they are ideal systems to study ecological impacts of multiple stressors at the local, regional and catchment scale (Tockner et al. 2007). Riverine floodplains are pulsed ecosystems with distinct flow, sediment, resource and thermal pulses and human modifications that truncate or amplify these pulses. That will have cascading effects on river-floodplain interactions by shifting the thresholds of connectivity, resilience or resistance - causing drastic regime shifts. Riverine floodplains integrate and accumulate multiple stressors at the catchment level, as reflected by distinct catchment fingerprints. The river-aquifer interface may provide a very useful filter for controlling mass fluxes between groundwater and surface water systems. However, the interface is complex, it has spatially and temporally variable efficiency, it is prone to clogging but it is also able to regenerate (Tellam & Lerner 2009). If the processes occurring in this zone can be understood, it may be possible to harness its attenuation. It may even be possible in future to improve properties and ecological status of this interface by active engineering or management, such as by river restoration, catchment management, or ecological manipulations. However, there is much work necessary before these possibilities may be fully realized, perhaps in several decades time, from developing the understanding of the processes through improving measurement and monitoring technologies to advancing modelling techniques.

Hydrological processes involve flows of matter and energy between different landscape components. Such connections between e.g. hill slopes and channel networks are sometimes understood at the scale of experimental sites, but not at larger catchment scales where many ecological processes are evident and management decisions are needed (Soulsby et al. 2006, Tetzlaff et al. 2007).

To understand the interactions between catchment hydrology and ecology, the concept of connectivity has obvious potential as a unifying theme where exchange of concepts and ideas can occur. Understanding ecological processes in the context of explicit catchment hydrological processes offers an exiting research frontier in catchment hydrology, which has the potential to provide many important insights (Tetzlaff et al. 2007). Opperman et al. (2010) proposes a conceptual model that captures key attributes of ecologically functional floodplains, encompassing three basic elements: hydrologic connectivity between the river and the floodplain, a variable hydrograph that reflects seasonal precipitation patterns and retains a range of both high and low flow events, and sufficient spatial scale to encompass dynamic processes and for floodplain benefits to accrue to a meaningful level.

2) Riparian zone processes

At a smaller scale, the riparian or hyporheic zone – the transition zone between surface water in rivers or streams and groundwater – is a connecting compartment between surface water and groundwater (Hyporheic Handbook 2009). It is a zone of intense biogeochemical activity and its ecological service is provided and sustained by the interaction of physical (e.g., transport of water and solutes), chemical (e.g., chemical reactions, sorption), and biotic processes (e.g., microbial transformation, bioturbation) by diverse and active communities (Brunke & Gonser 1997, Sophocleous 2002). In recent years, the interest in an improved understanding of exchange processes has substantially increased (Jones & Mulholland 2000), and this interest is driven by the recognition of the riparian zone as a compartment of utmost importance for maintaining the ecological function of running waters. This ecological function is affected by anthropogenic pressure on surface waters, for example by an increased probability of droughts and floods as an effect of climate change (Brunner et al. 2009). Exchange of surface water and groundwater with the riparian zone is closely linked to flow velocity, discharge, and water level in the river as well as to local and regional groundwater levels (Lewandowski et al. 2009). The fluctuation of groundwater levels in the vicinity of streams and rivers is strongly coupled to hydrologic events like floods and droughts (Humphries and Baldwin 2003). Riparian zones possess an unusually diverse array of species and environmental processes. The ecological diversity is related to variable flood regimes, geographically unique channel processes, climate shifts, and upland influences on the fluvial corridor. The resulting dynamic environment supports a variety of life-history strategies, biogeochemical cycles and rates, and organisms adapted to disturbance regimes over broad spatial and temporal scales. Innovations in riparian zone management have been effective in ameliorating many ecological issues related to land use and environmental quality (Naiman & Decamps 1997). Already in the earliest days of limnology, with regional limnology as the main field of research, it was quite clear that lake ecosystems also reflect the character of their catchment areas. The simple fact, that surface water and groundwater are carriers of solid and dissolved matter from catchment to lakes means that the shoreline should not be looked upon as a line of demarcation, but as a zone connecting terrestrial and aquatic ecosystems. A lake together with its catchment area constitutes, therefore, the primary ecological and management unit of a river basin. Water bodies are the mirrors in which the original state - and recent care, management and mismanagement - of the catchments are reflected (Bjork 2004).

3) Variability and heterogeneity at land – water interfaces

Heterogeneity of land surface (and subsurface) and atmospheric processes contributes to all aspects of the hydrological cycle. Understanding the types and sources of this heterogeneity is a fundamental component of both theoretical and applied hydrology and ecology (Tague 2005). Analysis of heterogeneity in hydrology, as in other sciences, seeks to characterize and ultimately to explain spatial and temporal patterns in all of its forms and the pathways by which the water is transported and stored. This leads to the concepts of ‘hydrologic landscapes’ (Winter 2001), and ‘flowpaths as integrators of heterogeneity in streams and landscapes’ (Fisher & Welter 2005). During bank filtration infiltration capacity depends on water extraction and hydraulic resistance of the bed sediments. Lake bed hydraulics may be especially affected by clogging, which is dependent on settlement of fine particles, redox potential and other factors. In the field most of these processes are difficult to quantify and thus, when calculating responses to the pumping of the water flux across the sediment surface is assumed to be linearly dependent on the hydraulic gradient. However, this assumption was not adequate, and Wiese and Nützmann (2009) described the leakage coefficient as spatially distributed and also temporally variant. In natural systems, the chemistry of floodplain waters is a function of the source of the water, which is influenced by geologic and geomorphic features of riparian wetlands. However, anthropogenic disturbances may alter both geomorphic features and the natural balance of water mixing in the floodplain. Cabezas et al. (2009) studied riparian wetlands and characterized their water characteristics in one reach of the Middle Ebro River to assess the hydrochemical functioning of the system. Moreover, geomorphic characteristics of riparian wetlands were also analyzed to interpret the results at broader spatio-temporal scales. Total dissolved solids, major ions (sulfate, chloride, sodium, calcium, magnesium, and potassium) and nutrients (nitrate, ammonium and organic nitrogen, and phosphate) depended upon the relationships between surface and subsurface water flows. Seasonal changes and geomorphic characterization indicated that a strong functional dependence of floodplain wetlands close to the main river channel is established, whereas most of the floodplain area remains disconnected from river dynamics.

Rates and reactions of biogeochemical processes vary in space and time to produce both hot spots and hot moments of element cycling. Biogeochemical hot spots are defined as patches that show disproportionately high reaction rates relative to the surrounding matrix, whereas hot moments are defined as short periods of time that exhibit disproportionately high reaction rates relative to longer intervening time periods. As has been appreciated by ecologists for decades, hot spot and hot moment activity is often enhanced at terrestrial-aquatic interfaces. Hot moments occur when episodic hydrological flowpaths reactivate and/or mobilize accumulated reactants. By focusing on the delivery of specific missing reactants via hydrologic flowpaths, a better mechanistic understanding of the factors that create hot spots and hot moments is demanded by McClain et al. (2003). Such a mechanistic understanding is necessary so that biogeochemical hot spots can be identified at broader spatiotemporal scales and can be factored into quantitative models. The authors emphasize the needs for further research to assess the potential importance of hot spot and hot moment phenomena in the cycling of different bioactive elements, improve our ability to predict their occurrence, assess their importance in landscape biogeochemistry, and evaluate their utility as tools for resource management.

Lakes, far from being homogeneous environments which we might expect, offer a rich and dynamic heterogeneity at multiple spatial and temporal scales that we are just beginning to understand. Starting with the centimetre scale pore water concentrations in lake sediments vary horizontally as well as vertically several orders of magnitude within few centimetres (Lewandowski et al. 2002) due to hydrologic impacts of chironomids (Lewandowski et al. 2007). On a within-lake scale, a complex set of phenomena such as internal waves and stream intrusions leads to both horizontal and vertical heterogeneity. Within a landscape, lakes often differ from each other both in their average characteristics and in their among-year dynamics. In landscapes dominated by groundwater flow, there is often more heterogeneity on lake characteristics and response to climatic events than in landscapes where exposed bedrock leads to rapid horizontal transport of water (Kratz et al. 2005).

4) Managing coupled natural and technical terrestrial - aquatic interfaces

The water balance of a landscape is a formative element of the natural ecosystem, in which man intervenes in a variety of ways, both direct and indirect (DFG 2003). On the one hand, river and lake restoration measures (e.g. aluminium addition to lakes, aeration of hypolimnetic water, river bank renaturalization) are strongly connected to terrestrial-aquatic interfaces, and, on the other hand, the use of surface and/or subsurface water resources (e.g. for bank filtration and irrigation) is also related to these interfaces. Examples to give an impression of the variety of measures that influence hydrological and biogeochemical processes at aquatic-terrestrial interfaces to demonstrate the importance of an integrated water resources management are presented in the following paragraph.

The construction of canals created new flowpaths that cut across historic stream channels, and the creation of artificial lakes produced sinks for fine sediments and hotspots for nitrogen processing. Further hydrologic manipulations, such as groundwater pumping, linked surface flows to the aquifer and replaced ephemeral washes with perennial waters. These alterations of hydrologic structure are typical by-products of urban growth in semiarid regions and create distinct spatial and temporal patterns of nitrogen availability. Constructed wetlands that mimic natural marshes have been used as low-cost alternatives to conventional secondary or tertiary wastewater treatment (Thullen et al. 2005). They showed that effective water treatment function and good wildlife quality within a surface-flow constructed wetland depend upon the health and sustainability of the vegetation, another ‘interface’ in the context described here. Although floodplains support high levels of biodiversity and some of the most productive ecosystems on Earth, they are also among the most converted and threatened ecosystems and therefore have recently become the focus of conservation and restoration programs across different countries and globally (Opperman et al. 2010). These efforts seek to conserve or restore complex, highly variable ecosystems and often must simultaneously address both land and water management. Thus, such efforts must overcome considerable scientific, technical, and socioeconomic challenges. In addition to proposing a scientific conceptual model, this paper also includes three case studies that illustrate methods for addressing these technical and socioeconomic challenges within projects that seek to promote ecologically functional floodplains through river-floodplain reconnection and/or restoration of key components of hydrological variability.

As mentioned in the introduction, bank filtration and artificial groundwater recharge are typical examples for coupled natural and technical ecosystems (see full report on CD). At a minimum, river or lake bank filtration acts as a pre-treatment step in drinking-water production and, in some instances, can serve as the final treatment just before disinfection. The main transformation (degradation) processes of diverse chemical compounds during this filtration occur at the surface water – groundwater interface sediments. Within the NASRI project (KWB 2005) a comprehensive biogeochemical process understanding has been developed and, with the help of modelling tools – used for water quantity and quality calculation and interpretation – principal transferability is achieved. These comprehensively integrated results serve as a "model" for identifying missing bricks in the coupling of natural and technical aquatic systems.

Further examples are presented in the full report on this application area (on CD) and include a) the role of the hyporheic zone in aquatic ecosystems, b) the role of biofilms in technical wastewater purification systems, c) lake restoration and the reduction of phosphorus, d) the removal of nitrogen levels in aquatic ecosystems, and e) the influence of wastewater treatment on aquatic ecosystems.

5) Summary

Towards a better understanding of terrestrial-aquatic interfaces in coupling natural and technical aquatic ecosystems four themes are of increasing interest for national and international research activities:

1. Connectivity of water and landscape
2. Riparian zone processes
3. Variability and heterogeneity of land-water interfaces, and
4. Managing coupled natural and technical terrestrial-aquatic interfaces.

The land-water interface may provide a very useful filter for controlling mass fluxes between groundwater and surface water systems. However, it is complex, having spatially and temporally variable efficiency, being prone to clogging but able to regenerate and also degenerate. If the processes occurring in this zone can be understood, it may be possible to harness its attenuation and in some instances flow-insulating capacity to very good effect. It may even be possible in future to improve these properties and ecological status of this interface by active engineering or management, such as by river restoration, catchment management, or ecological manipulations. However, there is much work necessary before these possibilities may be realized fully, perhaps in several decades time, from developing the understanding of the processes through improving measurement and monitoring technologies to advancing modelling techniques.

3.2 Application Area 2:

Process based understanding of hydrological-ecological linkages and feedbacks, e.g. focus on carbon cycling, nitrogen cycling

Introduction

Aquatic ecosystems are threatened by river regulation, diversion and over-abstraction of water, pollution, and spreading of exotic species. This does not only affect the aquatic ecosystems negatively, but also the ecosystem services these systems provide in terms of clean water, food production, pest and pollution control and so forth. Recognition of the escalating hydrological alteration of rivers and resultant environmental degradation has led to overarching policy frameworks, such as Integrated Water Resource Management (IWRM, Moriarty *et al*. 2004), to stress the importance of not compromising the sustainability of vital ecosystems when managing water resources. It is well recognised by scientists that the structure and function of a riverine ecosystem is determined by temporal variation in river flows (Poff *et al*. 1997). To protect freshwater biodiversity and the goods and services it provides, rivers need to be managed in a way that mimic components of natural flow variability; magnitude, frequency, timing, duration, rate of change and predictability of flow events (Arthington *et al*. 2006).

The concept of environmental flows has shifted from incorporating only the aquatic ecosystems dependence on flow regime to a more anthropogenic focus incorporating the human dependence on ecosystem services. '*Environmental Flows describes the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems'* (Brisbane declaration, 2007). Application Area 3 provides more details on the ecosystem services concept and socio-ecological linkages.

Ultimately the ecological condition in which rivers and their services to humans are sustained is essentially a socio-political decision. Ecosystem condition may be determined by a negotiated and 'desired' environmental flow by various stakeholders or a desired ecosystem condition may be set (e.g. by legislation), and the flow requirement is the water regime needed to sustain the ecosystems in that desired condition. Incorporating environmental flows in water management allows for a more comprehensive, fair and sustainable utilisation of natural resources (Naiman et al. 2002). Methods and tools for the participatory analysis, decision-making, and implementation of flow rules are presented in Application Area 4.

Addressing environmental flows is indispensable to achieving the objectives of IWRM. However, the knowledge on how to do this in practice is still inadequate, leading to insufficient flow prescriptions in managed rivers. Despite numerous studies on effects of human alteration of flow, and the scientific consensus of the importance of a natural flow regime, translating general hydrologic-ecological principles and knowledge into specific management rules remains a daunting challenge (Poff & Zimmerman 2010). One reason for this is that more specific quantitative data on hydrologic-ecological linkages and feedbacks are in short supply.

Water for public supply, irrigation and industry are examples of a direct use of water, whilst water for ecosystems provides benefits in an indirect way for people by supporting vital ecosystem services. The services maintained by ecosystems have real economic values that are generally neglected in management cost-benefit analyses. These values are linked to the products provided by ecosystems (e.g. fisheries) as well as the avoidance of costs related to declining profits, remedial measures, damage repair, and health care. Healthy aquatic ecosystems are also to be valued for their adaptability and greater resilience in the face of pollution threats and climate change. There are trade-offs in terms of benefits received between allocating water to direct and in-direct human uses. Addressing these trade-offs is necessary to maintaining the total long term benefits of aquatic systems.

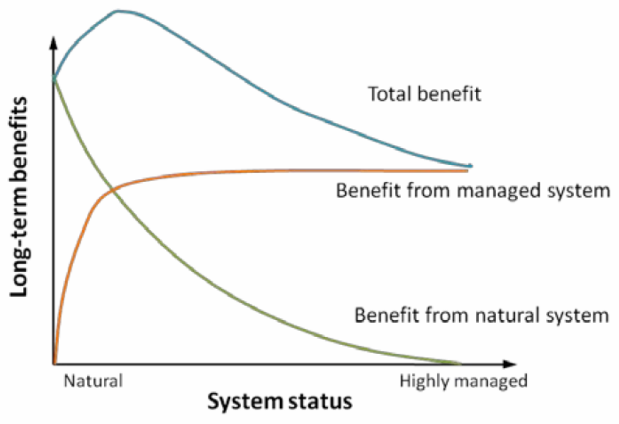

Figure 1. Trade-off between benefits from natural and modified systems

Figure 1 shows that modifications of natural systems continuously decrease the indirect benefits of the natural system (green line). At the same time, benefits from the highly managed system increase (orange line). Benefits from highly managed systems reach a plateau at some point, whilst the benefits of the natural system decline to zero at some point. The total long term benefits can be calculated by adding the benefits of the natural and highly managed systems. The total rises to a maximum before declining. It is at this point that the balance between naturalness and level of management is optimized (modified from Acreman 2001).

Recent research trends on hydrological-ecological linkages and feedbacks

Poff & Zimmerman (2010) did a thorough review of ecological responses to altered flow regimes. They found that good quantitative data of flow ecology relationships where generally lacking across organism groups. Some groups such as fish were better represented than others. They found no studies that reported primarily on ecosystem functional responses to flow alteration (e.g. riparian production, nutrient retention and cycling, stream metabolism, etc.), even though many ecological processes are clearly flow-dependent (i.e. Hart & Finelli, 1999; Doyle et al., 2005). They conclude that this absence points to an obvious research gap when studying effects of flow alteration. A reason for this could be the often short-term, 'snapshot' nature of biological sampling done to document ecological change in flow-altered systems.

Riparian, floodplain and wetland productivity and hydrogeomorphology is linked to processes such as nitrogen retention and carbon storage and transport. The main driver behind these linkages is the flow regime (Tabacci et al. 1998). Given the importance of wetlands and aquatic ecosystems for the cycling of nutrients and carbon, it is important to understand how these linkages look like and how different water management options affect processes, to include the potential value when balancing trade-off in water use. Finally, methodologies for the assessment of hydrological-ecological linkages and feedbacks vary from simple rules of thumb to data-intensive computer models (O'Keefe and Le Quesne 2009; Poff et al. 2010). While the former methods are often too simplistic to the adequate assessment of flow-ecology relationships, the application of the latter require high resources which can not be provided in many parts of the world. The ELOHA framework is a recent approach to find a balance between level of detail and resource effectiveness by defining river typologies that allow flow assessment at the regional and national scale (Poff et al. 2010). The research gaps and trends mentioned above are elaborated below.

1) The links between hydrologic regime and riparian, floodplain and wetland productivity.

Riparian productivity is often lower in rivers where flow is regulated (Jansson et al. 2000). The main reason for this is hypothesised to be the lack of floods bringing nutrients to the riparian vegetation. For example flood frequency is important for the productivity and decomposition of plants. Padial & Thomas (1998) showed that floods, even of short duration, increase the decomposition rate and the nutrient cycling relative to dry conditions. Flow regime has an impact on growth response in riparian forests trees. Anderson et al. (2008) found a parabolic curve response to flooding, suggesting that there is an optimal flooding regime to promote growth. The relationship between riparian vegetation and flow regime may also differ between various functional groups (Robertson et al. 2001).

2) Hydro-ecological links in carbon cycling

The capacity of wetlands to store carbon is drawing increasing attention around the globe (Lenart 2009). Peat lands store 30% of the world's terrestrial soil carbon (Chivers *et al*. 2009). Leading experts and politicians alike argue that wetlands, in particular peat forming wetlands, should qualify as carbon credits in a global climate treaty, similar to that of forested land in the UN-REDD program. There was a push for this before the COP15 meeting in December 2009, but such a program was not adopted. A literature analysis showed a slightly increasing trend in papers that contained the search terms "wetland" and "carbon sink", and "wetland" and "carbon cycling" (many of the records in these two searches are likely the same, cf fig. 4 in the full report; on CD).

However the role of wet lands in carbon sequestration is not clear-cut (Bridgham et al. 2006). Wetlands are also contributors of green house gasses to the atmosphere, primarily in the form of methane. Whether wetlands are carbon sinks or net contributors of green house gasses varies from site to site, but how this variation looks like is poorly known (Lenart 2009). Information on this across regional gradients would add to the understanding wetlands plays in the global carbon cycle. There is also a need for further knowledge on how flow management and water allocation affects carbon sequestration within a watershed. A study on water table and temperature manipulations in an Alaskan fen suggests that draught will decrease ecosystem carbon storage, while inundation will increase it by stimulating plant growth (Chivers et al. 2009). Methane and CO2 dynamics is also influenced by soil property (Altor & Mitsch. 2008) and vegetation type (Miller & Fujii 2010). Increased knowledge on how hydrologic regime links with CO2 sequestration and methane emission across larger spatial scales and between various types of wetlands would be valuable addition to incorporate in flow management schemes.

3) Hydro-ecological links in nitrogen cycling

Human activities have disrupted the natural biogeochemical cycling and doubled the rate of nitrogen input to terrestrial systems (Vitousek *et al*. 1997). This has in many cases led to greatly increased nitrogen loadings in rivers, estuaries and oceans. Floodplains are important sites for denitrification and nitrogen retention and it is well known that constructed wetlands in the drainage area and riparian buffer zones can reduce the amount of nitrogen run-of that reaches the stream and estuary ecosystems. In monetary terms, denitrification and nitrogen retention is calculated to have a great net worth. For the Danube, nitrogen processing was estimated to respond to half the wort of all ecosystem services combined (Gren *et al*. 1995). Wetland restoration and creation is increasingly being used as a mean to protect against harmful run-of, but restoration of flood plains is lagging behind. It is estimated that 90% of flood plain forests have been lost in Europe and North America (Tockner and Stanford 2002) due to flood protection measurements, damming and regulation of flow, and altering former floodplains to agricultural land.

Fluctuating water levels creates aerobic and anaerobic conditions that are effective for enhancing denitrification (Reddy and Patrick, 1975; Groffman and Tiede, 1988). Nutrient cycling and export in streams and rivers should vary with flow regime, yet most studies of stream nutrient transformation do not include hydrologic variability (Hall et al. 2009). It is not well known how alteration to natural flow regimes affects floodplain denitrification (Gergel et al. 2005), especially over larger scales. Kadlec (2010) found that nitrogen removal was enhanced in wetlands maintained by water pumping when introducing hydrological event (pulsed flow) compared to steady state wetlands. Hunter & Falkner (2001) found that more denitrification occurred in forested wetlands where the natural flow regime is maintained compared to restored wetlands where the hydrologic regime had not been established. Gergel et al. (2005) simulated the effects of flood alteration through upstream dams and setback levees on a generalized flood plain, mimicking features typical for Upper Mid-western US. They found that dams reduced nitrogen processing more than levees. Levees increased denitrification rates, but reduced overall denitrification through reduction in inundated area. A study on soil nitrogen cycling in riparian wetlands across a European climatic gradient found that water table elevation was the main driver on nitrogen cyling. Neither climatic factors nor vegetation type seemed to significantly affect denitrification rates (Hefting et al. 2004).

Pinay et al. 2002 raises some scientific challenges to improve our knowledge on the ecological consequences of changing water regimes on nitrogen cycling. These challenges mainly relate to; cumulative impacts of regime changes i.e. combination of changes in flow variables, scale of appraisal of these changes, and the relative impact of natural and human changes.

4) Methodological framework for environmental flow assessment at large scales

The threat of over-allocation of rivers is rising due to the accelerating pace of global and climate change (cf. Palmer et al. 2008). Water management has to deal with an increasing uncertainty that demands innovative approaches to deal with societal pressure on ecosystems (Pahl-Wostl, 2007). Understanding the linkage of environmental flow regimes to ecosystem functions and further to environmental services is a complex task that requires in depth empirical research to generate reliable knowledge and flow standards. However, long-term scientific research is often not possible as resources are often limited, and water management demands timely results (Hanssen et al. 2009). The use of ‘rules of thumb’ is one approach to come to quick results with limited resources. Flow standards are therefore calculated by using fixed percentages of flow components like the median annual flow, base flow, or surface runoff (e.g. Cullen 2001; Smakhtin et al. 2004). These simplistic and static approaches are more and more criticized as they ignore the full complexity of the natural system and are not based on empirical research (Richter et al. 1996; Poff et al. 1997; Lytle and Poff 2004; Arthington et al. 2006). Given the resource intensity of quantitative assessment methods, Poff et al. (2010) argue that a river-by-river assessment of environmental flows will not keep pace with global and climate change, even though methodological knowledge from individual case studies is advanced. They propose the synthesis of existing knowledge into a scientific framework for the assessment of environmental flows at larger scales, namely regional up to national scales. This generic approach comprises the identification of classes of natural rivers in a region based on ecological responses to flow alteration (cf. Arthington et al. 2006). Impaired rivers are sorted in these classes by estimating the pre-disturbance flow metrics or applying landscape or climate characteristics. The framework builds on the notion that flow-ecological relationships are not necessarily exclusive to single rivers but may be applicable to rivers of a particular hydrological type, such as arid-zone or snow-melt rivers (Poff and Allan, 1995). A class represents a “management unit” and provides a guideline for the implementation of environmental flows based on empirical knowledge gained in other rivers belonging to the particular class. Quantitative relationships between flow-alteration and ecological response have to be developed along the gradient of natural to impaired river flow regimes in order to be able to set environmental flow standards. Thus, flow rules can be tailored to management goals about the status of rivers ranging from the preservation of natural flow regimes, to restoration of highly modified rivers (Arthington et al. 2006).

5) Summary

Several gaps in scientific knowledge on understanding of hydrological-ecological linkages and feedbacks focusing on floodplain, wetland, and riparian productivity, and carbon and nitrogen cycling have been identified. The most important is how these processes vary with flow regime, and how human alteration of flow affects these processes. Most studies found were site specific or focusing on only one type of system.

A research program that focuses on larger spatial scales and across different types of hydrological landscapes, modelling flow-ecology response relationships would serve as valuable decision support system in water management. Results from such a program could also feed into a program focusing on functional linkages of coupled natural and technical aquatic ecosystems (i.e. rural-urban linkages). Preferably such a research program would run over several years in order to capture not only spatial, but also temporal variability in the driving variable; flow. However, also smaller projects would add valuable knowledge in obtaining a fuller understanding how flow alteration affects these ecosystem services.

3.3 Application Area 3:

Process based understanding of social-ecological linkages and feedbacks: how do societies depend on ecosystem services?

Introduction

In recent history there has been growing recognition of the benefits humans derive from ecosystem services (e.g. Baron et al. 2002, Daily and Matson 2008). By now the human dependency is a widely acknowledged fact and was reconfirmed by the Millennium Ecosystem Assessment Synthesis Report in 2005, which highlights the detrimental effects of ecosystem degradation on the services provided and, accordingly, on human society.

With increasing pressures on ecosystem services due to global change, specifically population growth and climate change, there is the risk of growing imbalances, which need to be addressed (e.g. Jackson et al 2001). In a recent IUCN publication it is advocated to make use of natural infrastructure since intact watersheds, floodplain and coastal areas can contribute to reducing people’s vulnerability and increase adaptive capacity through water storage, flood control and coastal defense. This forms the basis for reducing trade-offs and building resilience when combined with good governance and learning, whereas engineering solutions alone are not sufficient and can even have detrimental effects on resilience due to resulting environmental damage (see also Folke et al. 2004, Folke et al 2002).

Adaptive management and governance of resilience are thus needed to restore degraded ecosystems so that these are capable of delivering essential services even when changes occur (e.g. Folke et al. 2004, Adger et al (2005). Nelson et al (2007) suggest a systemic resilience framework to analyze adaptation processes and identify policy responses. With this framework they also go beyond the, so far, more common actor-centered approaches and link the social system to the ecological in order to identify the mechanisms of adaptation creating a learning environment. Consequently, a resilient social-ecological system may make use of crisis as an opportunity to transform into a more desired state (Folke et al 2005). The importance of addressing future challenges in an integrative manner is also highlighted by other studies, e.g. in a development context (Brown and Upmanu 2006), or with a special focus on the role of communities in ecosystem management (Fabricius et al 2007). Fabricius et al 2007 provide a synthesis of papers from a special issue titled “Strengthening People’s

Adaptive Capacity for Ecosystem Management and Human Well-being" categorizing different types of communities in relation to how they cope with change. Results show that those communities able to improve their adaptive capacity can deal with challenges, trade-offs between short and long term effects on their well-being, and implement ecosystem management rules safeguarding ecosystem services.

According to Zehnder et al (2003) a fair distribution of freshwater between humans and nature is one of the major future challenges. It is evident that the social and ecological systems are closely intertwined and that a sound knowledge base and good understanding of the underlying processes and dynamics of social-ecological linkages are needed to arrive at sustainable ecosystem services management that equally caters for the human and environmental water needs.

Current state of research

1) Understanding of social – ecological linkages

The concept of ecosystem services aims at finding solutions to simultaneously conserve biodiversity and promote human well-being (Tallis et al 2009). According to Braimoh et al (2009) an underlying assumption of the Millennium Ecosystem Assessment (MA) is that due to the interconnectedness of environmental and human well-being, improvement of the former will lead to progress of the latter as well. However, this does not fully take into account the possible trade-offs. When making use of one ecosystem service others may deteriorate as a result.

Furthermore, Tallis et al (2009) point out that only a few examples of successful win-win cases are known to date and that no guiding theories exist. According to Farber et al (2002) the chances of achieving win-win situation are likely to become even scarcer when looking at it from a fully global perspective. To gain a better understanding of what is currently being implemented in the field in order to integrate conservation and development goals they analyzed a total of 103 ecosystem service projects in over 30 countries. This explorative study purely documented and categorized what has been done within the scope of these projects in the context of developing countries and is only a first step in building up a knowledge base for better understanding specific social-ecological linkages. The actual outcomes of the implementation projects were not monitored by the researchers and only about a third of the projects monitor their own work.

Overall, despite their recognition many social-ecological linkages are not understood very well as they are very complex and information on the underlying dynamics and relationships are still lacking (e.g. Jewitt, 2002, Butler and Oluoch-Kosura 2006, Carpenter et al. 2009). This is also true for the ecological and social systems when looked at as separate entities. Various authors highlight that even though a lot of progress in research is being made the ecological understanding of ecosystem functions and services is still limited (e.g. Kremen and Ostfeld 2005, Daily and Matson 2008) (see also chapter on 'Process-based understanding of hydrological-ecological linkages and feedback'). In a recent publication Bennet et al (2009) address this lack of understanding and develop a typology of relationships among ecosystem services in order to drive forward research in this field.

In relation to the social system Butler and Oluoch-Kosura (2006) point out that access to ecosystem services is not equally distributed. But even in cases of sufficient access and use of available services well-being is not automatically improved. Additional factors, such as income or the level of democracy, also play an important role in determining human well-being. Butler and Oluoch-Kosura (2006) further argue that the 'causality between ecosystem services and well-being is bidirectional', which means that the state of society also influences the state of ecosystem services.

2) Managing trade-offs between human and environmental water needs: the role of governance

Understanding the causal relations among different ecosystem services as well as between the ecological and social system is essential for being able to manage trade-offs.

Based on different studies dealing with trade-offs Braimoh et al (2009) provide an overview of the two main forms of trade-offs: spatial and temporal. Spatial trade-offs imply that through the use of one ecosystem service in a specific location another service is reduced or even lost in that same location or in the immediate surrounding. An example is the use of water for irrigation which limits the availability of water for other purposes. Spatial trade-offs also describe situations in which people in one area benefit from ecosystem services from a distant place, e.g. between rural and urban areas or between countries.

Temporal trade-offs often refer to intergenerational imbalances. Making use of ecosystem services to meet current needs may compromise the functioning of that and interlinked ecosystem services in future. Often the provisioning services are exploited in the short-term at the expense of long-term regulating or cultural services.

Falkenmark and Rockström (2004) stress those sustainable solutions, which succeed in balancing the water needs of humans and nature, strongly depend on our ability to manage trade-offs and offer an ecological approach to find a balance. Daily (2000) promotes the so-called Ecosystem Services Framework to systematically characterize ecosystem services at the local, regional, and global level integrating biophysical and social dimensions. Overall, the problem of trade-offs is well recognized and associated assessment and management challenges are already being addressed. Modern holistic environmental flow assessment methods offer ways of evaluating trade-offs accounting for the fact that management choices play a vital role in determining the type and scope of spatial as well as temporal trade-offs (e.g. Rodríguez et al 2006). In this overall context participatory approaches play an increasingly important role. The current state of research on this is presented in the chapter on 'Management tools for implementation of environmental flows'.

As was already pointed out in the interim report it is plausible to assume that water governance is a central determinant of trade-offs between ecosystem services (e.g. Braumann 2007, Pahl-Wostl 2009). Cumming et al (2006) found ecosystem services and governance are interlinked at various scales and that losses of ecosystem services are often caused by a mismatch of scales between ecosystem processes and governing institutions.

So far only little research is available that focuses on the linkages between water governance and ecosystem services, specifically analyzing the role of governance regimes and how these influence trade-offs at different levels and the state of the aquatic environment. Water governance is understood here quite broadly as defined by the UNDP: "Water governance refers to the range of political, social, economic and administrative systems that are in place to regulate development and management of water resources and provisions of water services at different levels of society." (www.undp.org/water/about_us.html)

Brunckhorst (2002) emphasizes how resource governance can mediate between the needs of society, the economy, and ecosystem services to achieve sustainability and a continuation of ecosystem functions and services. The importance of good governance for managing freshwater ecosystems is also highlighted by Postel (2003). She looks at the trade-offs between natural and human water needs and calls for a change in the mindset as the water needs of ecosystems have been neglected so far, which is endangering the services freshwater ecosystems provide. Other studies linking governance and aquatic ecosystems tend to focus on marine ecosystems and fishery, which can be interpreted as a manifestation of their economic value. Ruckelshaus et al (2008), for instance, analyze marine ecosystem management and point out that governance structures play an important part in implementing ecosystem-based management. Further elaborations on the importance of governance are found in other articles on marine fishery. Hanna (1999) highlights how governance can contribute to sustainability in marine fishery and points out some functions that fishery governance must fulfill in order to achieve this goal. Juda & Hennesey (2001) focus on governance and the role it plays for the management concept of large marine ecosystems (LMEs) which was emerging at the time. They point out how ecosystem productivity, fishery, and ecosystem health have received most attention when analyzing LMEs whereas the socioeconomic dimension and governance have often been neglected in comparison. Accordingly they highlight the governance framework within which ecosystem-based management takes place and propose to develop governance profiles that present and analyze existing frameworks and call for further studies that look at governance and ecosystem use.

3) Valuation as a tool to safeguard ecosystem service functionality

Managing ecosystems services is closely associated with the valuation of these services, which is reflected in the Scopus literature: the search terms ‘ecosystem service’ and ‘water’ and ‘management’ generate a number of scientific articles addressing questions of valuation. Braumann et al (2007) highlight the intrinsic value of ecosystem services because humans benefit from their use independent of a monetization. However, as pointed out by Villa et al (2007) many of the studies focusing on valuation refer to monetized values which can then serve as incentives for conserving ecosystem services as in the case of Payments for Ecosystem Services (PAS) schemes (e.g. Jacka et al 2008).

Valuation is therefore an important supporting tool in decision-making especially with regard to water allocation. In this context Postel and Thompson (2005) draw attention to the fact that “natural ecosystem services lie outside the traditional domain of commercial markets” and are therefore “undervalued and underprotected”. Similarly Korsgaard et al (2008) address how environmental water needs are often disregarded and present an assessment approach which focuses on ecosystem services stressing the links between environmental flows and socio-economic values (see also chapter on ‘Management tools for implementation of environmental flows).

Altogether, there are many different approaches to valuation of ecosystem services and assessment frameworks. In a critical review Turner et al (2003) analyze these and find that: i) aquatic ecosystems received least attention, ii) the majority of studies was limited to single function valuation, and iii) only few monitored changes over time. The importance of valuating ecosystem service across temporal and spatial scales is also highlighted by Hein et al (2006). Additional perspectives on ecosystem service valuation are introduced by Kumar and Kumar (2008) who focus on the psycho-cultural dimension and Bhagwat (2009) who examines the spiritual significance of ecosystems and their services. Apart from that Meyerson et al (2005) draw attention to the fact that perceptions of the importance of ecosystem services to society can vary, which must be addressed appropriately by decision-makers.

The importance of valuation as a tool for managing ecosystem services and trade-offs seems to be widely agreed on and a multitude of approaches to valuation exist. Despite the clear advances of research on ecosystem service valuation Liu et al (2010) conclude that further syntheses of tools, skills and methodologies across the different disciplines are needed. As already pointed out in the interim report the future challenge is to combine existing approaches to find ways of operationalizing valuation consistently and reproducibly. Furthermore, Plummer (2009) draws attention to the fact that assigned values are site-specific and benefits are therefore difficult to transfer from one location to a similar one. One of the latest approaches to ecosystem valuation is the so-called ‘sequential decision support system’ (Turner et al 2010, Morse-Jones et al 2010) which takes these and other difficulties into consideration and is specifically aimed at practitioners.

4) Summary

The literature review underlines the importance of social-ecological linkages and human dependencies on aquatic ecosystem services. At the same time, it is evident that there are still significant research gaps, which need to be addressed in future. In summary the main gaps identified are related to our understanding of social-ecological linkages and trade-offs, as well as ecosystem service management including valuation and the role of governance.

For a better understanding of social-ecological linkages and trade-offs it is essential to improve the empirical database to be able to quantify environmental and human water needs, further analyze linkages within the ecological system, as well as relevant social factors and their interrelations that play a role in supporting human well-being. In this regard it is important to analyze multiple cause and effect relations in both directions between the social and ecological systems across temporal and spatial scales. Furthermore, methods to transfer results from one area to a comparable one without neglecting the context-specific particularities are needed.

Better understanding of the social-ecological linkages and the underlying dynamics and processes forms the fundamental basis for managing ecosystem services sustainably.

Additionally, the implementation of ecosystem service projects must be monitored and evaluated in order to be able to identify principles for best practice. Overall, there is a need for mainstreaming and operationalizing approaches to managing ecosystem services including valuation. Finally, in order to arrive at sustainable solutions the role of governance must be analyzed in more detail. This would also help to identify critical factors for adaptive capacity of social-ecological systems, which will be needed when facing the challenges of global change.

3.4 Application Area 4:

Management tools for implementation of environmental flows (focussing on stakeholder involvement)

Introduction

Environmental flow rules have to be determined using a defensible approach that is based on best-available knowledge. Over 200 methods exist but standard methods are still lacking that allow for defensible and resource-effective assessment. The methods used for environmental flows assessment have developed from simple rule-of-thumb methods for the preservation of commercially important fish species to holistic methods that encompass ecologic as well as socio-economic aspects (Tharme 2003). The Milestone Report of the BMBF-project (Pahl-Wostl et al. 2010) provides an overview of available methods and their history of development (see also: Tharme et al. 2003, Dyson et al. 2003).

Despite extensive development and testing of methodologies, examples for the successful implementation of environmental flow rules are rare (O'Keefe and Le Quesne 2009; Poff et al. 2010). Experts in the BMBF project workshop held in February 2010 in Osnabrück concluded that the main obstacle for of the environmental flow concept to have a real impact is related to the implementation of flow rules. The following topics have been determined to be the scientific and practical challenges in respect to flow implementation that are also reflected in the major findings from recent publications on environmental flows and international conferences in Australia (Garrick et al. 2008) and South Africa (Garrick et al. 2009):

1) Holistic assessment methodologies are required to examine links and trade-offs between economic, environmental and sociological benefits of environmental flows (King et al., 2003, Korsgaard et al. 2008).

2) The demand for predictive assessment of flow-ecology relationships requires long-term research activities and, thus, can stall implementation of flow rules. Adaptive management

approaches for environmental flow assessment regard flow rules as flexible guiding principles that need to be adapted to new insights derived from experiments instead of definite standards (Poff et al. 2003; Richter et al. 2006; Garrick et al. 2008, and 2009).

3) Implementation of flow rules depends upon the commitment of stakeholder groups towards measures or policies. Ecosystem services need to be valued by stakeholders including scientists, policy makers, water users and interest groups. Therefore, methods for stakeholder involvement in the valuation of ecosystem services as well as setting and implementation environmental flows are needed (O'Keefe and Le Quesne 2009; Garrick et al. 2008, and 2009).

4) Water governance reforms are needed to find effective institutional structures to assure implementation of environmental flows and preservation of ecosystem integrity (Garrick et al. 2008, and 2009). Research on governance of environmental flows includes legislative (e.g. property rights), economic (e.g. water markets), and social aspects.

Recent trends in environmental flow research

The following section will review recent developments concerning all main impediments identified for the implementation of environmental flows. A special focus will be devoted to methods and frameworks that address participatory research on environmental flows.

1) Holistic methods for integrated environmental flow assessment

Another important methodological development is related to holistic environmental flow assessment methods that incorporate hydrological, hydraulic and habitat simulation models (Dyson et al. 2003). The origin and Application Area of methods is quite diverse with the Instream Flow Incremental Methodology (IFIM) developed in the US (Bovee, 1986; Bovee et al., 1998), the Holistic Method mostly applied in Australia (Arthington et al. 1992, Arthington 1998), and the Catchment Abstraction Management Strategies (CAMS) from the UK Environment Agency (DETR and Welsh Office. 1999). The DRIFT methodology (Downstream Response to Imposed Flow Transformation) originates from South Africa, and is the only method that includes societal consequences of flow alteration. It bases on the Building Block Method (BBM) (King and Louw, 1998; King et al., 2000), and consists of four modules: a biophysical, socio-economic, scenario as well as economic module (King et al., 2003). A common feature of holistic methodologies is the incorporation of knowledge from a range of disciplines through expert panels and/or the initiation of public participation processes (Dyson et al. 2003). Scenario analyses allow for analysis of consequences of flow alteration that can support decision-making on the desired state of a river and the related flow regime (King et al., 2003). Koorsgard (2006) developed a Service Provision Index (SPI) that constitutes a modification of socio-economic module of the DRIFT methodology. The SPI links ecosystem services to flows, and thus allow for the valuation of environmental flows (Korsgaard 2006, Korsgaard et al. 2008).

2) Adaptive management approach

An adaptive management approach is promoted by various scholars as a meta-framework to allow for immediate management action under situations of incomplete knowledge on flow-ecology relationships, for instance due to knowledge gaps, limited resources or time-pressure (e.g. Richter et al. 2006, O'Keefe and Le Quesne 2009).

Holling (1978) describes the adaptive management approach as "an integrated, multidisciplinary and systematic approach to improving management and accommodating change by learning from the outcomes of management policies and practices". Using an adaptive management approach, environmental flow rules are considered as hypotheses rather than ultimate truths. This understanding fosters learning about the water system through iterative improvement of environmental flow rules. Thus, controlled experiments with environmental flows can provide valuable insights about the responses of riparian ecosystems (Poff et al. 2003). Richter et al. (2006) developed a collaborative and adaptive management framework for the setting of environmental flow recommendations. Even though the application of data-intensive simulation models is explicitly considered to be important for the understanding of flow-ecology linkages, the framework applies exclusively conceptual qualitative models to highlight that adaptive management of environmental flows does not necessarily depend on quantitative modelling. The 5-step process comprises: (1) an orientation meeting in which scientific, political and other stakeholders meet to discuss the organization of the overall process, and define sources of data relevant to the flow assessment; (2) preparation of a literature review and summary report that contains existing data and knowledge on the water system; (3) a flow recommendation workshop held by scientists from multiple disciplines to quantitatively define environmental flow rules based on collected information; (4) implementing the recommendation and monitoring of effects through a carefully designed monitoring programme including gauges and ecosystem indicators; and finally (5) initiation of data collection and research programs that evaluate the outcomes of the implemented flow rules and gaps in knowledge and data. The steps 3-5 are continuously implemented to improve knowledge on the hydro-ecological system and refine environmental flows.

Acreman and King (2003) outlined a 10-step strategy for capacity building in Tanzania which contains also elements of general relevance (see Dyson et al. 2003). They propose an adaptive management approach through testing of flow assessment methods and implementation through a case study in a high-conflict area. In addition, cooperation between experts from different disciplines as well as international cooperation and field visits to learn from others' experiences are considered to be important. Further steps contain the instalment of a national database of knowledge on environmental flows, as well as a communication strategy to spread information to all relevant sectors and the public (Acreman and King 2003).

Besides being an experimental approach, adaptive management strives for the increase of adaptive capacity of human-environment systems (Baron et al. 2002; Pahl-Wostl 2007). Adaptive capacity can be defined as "the ability of a socio-ecological system to cope with novelty without losing options for the future" (Folke *et al.*, 2002). In respect of environmental flows, the Ecohydrology concept from the UNESCO aims at the purposeful usage of ecosystem processes to fulfil water-related services for society. Thus, water management can make use of ecosystem properties as natural infrastructure similar to engineering approaches to fulfil its goals (Zalewski 2002). Through protection of ecosystem functions, the capacity of the ecosystem rises to absorb human impacts. For instance, wetlands can play an important role in denitrification processes originating from the application of fertilizers in agriculture (Zalewski 2000). 'Natural infrastructure' is a similar concept that demand research on ecosystem functions and related services to allow water management to implement the most effective set of technical and conservation measures (Smith and Barchiesi, 2009).

In addition to enhance the adaptive capacity of ecosystems, adaptive management lays particular importance on collaborative management that includes multiple stakeholder groups. Social learning increases the adaptive capacity of stakeholder groups that can be defined as the ability to react to problems through informal learning processes and collective action (Pahl-Wostl et al. 2007). However, participatory approaches in environmental flow assessment are rare. Literature dealing with adaptive management approaches place more emphasis on experimental component of adaptive management than on stakeholder involvement. The next section provides a review of participatory management tools for environmental flow assessment and implementation.

3) Participatory management tools

The environmental flow requirement in a river system is often a negotiated trade-off between multiple water users including the environment (Naiman et al. 2002). Although the need for stakeholder involvement in this negotiation process has been highlighted quite often (e.g. Poff et al. 2003; Rogers 2006; O'Keefe and Le Quesne 2009; Smith 2009), only a limited number of articles provide concrete approaches that specify the form and organization of stakeholder involvement. Experiences with the implementation of the WFD have shown that stakeholder involvement needs to be well-planned to avoid frustration, for instance in case that real participation in decision-making is promised but only information or consultation realized (Acreman and Ferguson 2010).

The research and implementation process of environmental flows provide different opportunities for participation, and can be divided into the following steps:

1) Definition of objectives for water management, and valuation of services provided by the water system

2) Analysis of ecosystem services – environmental flow relationships

3) Strategy development and implementation of environmental flows

4) Monitoring of effects of flow alteration, and strategy revision

An overview of participatory approaches concerning these steps of flow assessment and implementation is provided in the following sections.

Setting objectives and valuation of ecosystem services

To be accepted and effective, environmental assessments need to be incorporated in a basin-wide water management process. The definition of objectives for river management constitutes a social judgement that implies the valuation of services provided by the aquatic ecosystem. Thus, water management in general and environmental flow assessment in particular require the participation of multiple stakeholders comprising scientists, politicians, water users, and other affected groups (Poff et al, 2003; Rogers 2006; O'Keefe and Le Quesne 2009; Smith 2009).

The overall objectives for water management are often predetermined by water legislations. In South Africa objectives are set according to ecological management targets (Rogers and Bestbier 1997), and the EU WFD demands a good status of all water bodies (EC 2000). However, the transfer of these more general targets to specific and operational management goals permits the involvement of stakeholders.

The "objectives hierarchy" is a method that helps to connect aims and visions of non-specialist stakeholders with the often more technical knowledge of experts (O'Keefe and Le Quesne 2009). The process starts with the development of a vision statement that expresses the goal of river management by the stakeholder group. This often more general and unspecific vision is afterwards translated to a high-level objective that includes operational goals for water managers. Finally, sub-objectives and measureable indicators are determined to further specify management goals. A complementary approach is the "thresholds of potential concern" concept that sets upper and lower limits to operational indicators (Biggs and Rogers, 2003). In case of reaching a threshold level, a predetermined management response is applied comprising the analysis of causes, and the implementation of countermeasures.

Ecosystem functions and services that are provided by riverine ecosystems are manifold (see MEA 2005). Economic methods for the monetary valuation of ecosystem services are widely applied. Forslund et al. (2009) provides an overview of methods and their potential and limitations to be used for environmental flow assessment. Despite various shortcomings of economic methods for valuation, they conclude that each method has the potential to raise awareness about roles and values of ecosystem services. The choice for ecosystem services and functions/processes to protect or restore requires the involvement of beneficiaries of services as well as individuals and organizations whose actions impair their provision (Chee

2004). In addition to a clear vision about desired ecosystem services, Chee (2004) suggests an adaptive approach that includes learning about the problem and dynamics of the system resulting from the application of different measures. Risks and uncertainties involved have to be assessed, and a discussion about solutions and trade-offs between stakeholders facilitated. The combination of tools like discourse-based methods, simulation modelling, probabilistic risk assessment, multi-criteria analysis, and scenario planning are approaches that can facilitate participatory processes dealing with the valuation of ecosystem services (Chee 2004). The DRIFT methodology (King et al., 2003) fulfils most of these demands, especially in combination with the Service Provision Index (SPI) developed by Korsgaard (2006) (see section 2.1). The aim of the DRIFT methodology to predict future developments of human-technology-environment systems complies with the traditional command-and-control paradigm in water resources management. However, adaptive management approaches are more suitable to deal with inherent complexity of the system to be managed (Pahl-Wostl 2007). Thus, soft systems methods and group model building techniques could be suitable and innovative methodological approaches for environmental flow assessment.

Analyze flow-ecology relationships

While the valuation of ecosystem services is a social process, the study of ecosystem functions that produce these services requires a scientific approach. Various scientific methods exist for the assessment of impacts of flow alteration on the ecosystem (see Dyson et al. 2003; Tharme 2003; Arthington et al. 2006). Even though the analysis of flow-ecology relationships are more a scientific task, the specification of flow rules requires the assessment of risks and trade-offs that, in turn, makes the inclusion of the public in the decision-making process necessary. Participatory methods for the definition of environmental flow rules are rare. One example is the "flow-response graph" that helps to define acceptable and adverse resource impacts (Poff et al., 2010).

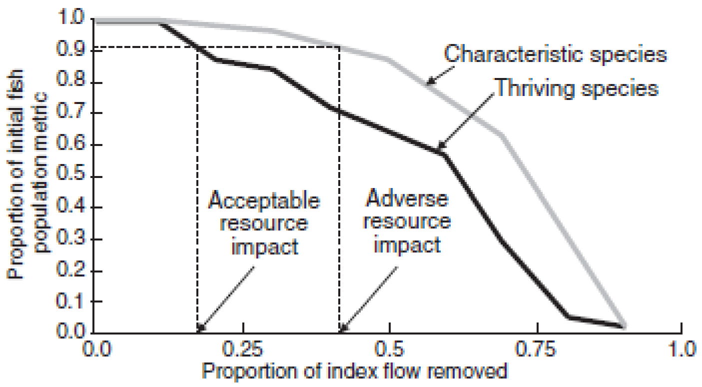

Figure 2: Progression from flow alteration–ecological response relationships to environmental flow standards (Poff et al. 2010, modified from MGCAC, 2007).

Figure 2 illustrates the dependency of the fish population (differentiated between thriving and characteristic species) on allocated water for a stream type in Michigan, USA (MGCAC, 2007). A stakeholder committee decided that a 10% decline in the thriving population is an acceptable impact, while a 10% decline in the characteristic population is an adverse impact. Based on these definitions, environmental flow rules can be derived for operational management by selecting the corresponding flow alteration on the x-axis (Poff et al. 2010).

Strategy development and implementation of environmental flows

The application of participatory methods is considered to increase commitment of stakeholders towards the implementation of flow rules rather than top-down decision-making. However, a concerted strategy of technical, economic, and political measures is necessary to achieve flow targets.

In modified river basins, the installed infrastructure can impede the implementation of environmental flows. For instance, the outlets of dams may restrict the maximal volume of flows (O'Keefe and Le Quesne 2009). New dam designs need to consider environmental flows as later re-operation are costly and sometimes even impossible. In addition to the technical design, structures like roads and houses as well as high-value agriculture can impede the implementation of high flows. Low flows can also be inhibited in case that high flow volumes are required for the dilution of wastewater (Richter and Thomas 2007).

Impoundments such as dams or weirs have been constructed for many purposes - like water supply hydropower generation, or flood control – while the assurance of environmental flows was seldomly considered (Dyson et al. 2003; Acreman et al. 2009). Thus, dams usually involve major changes in the natural flow regimes up to total elimination of the natural variability. This caused a widespread impairment of riverine ecosystems and ecosystem services provided (WCD 2000; MEA 2005). In the UK and similarly in France and Brasil, most of the dams (about 70%) constantly release about 16% of the mean flow throughout the year. Only a few dams realize variations of the flow release, while other impoundments regularly do not release any volumes at all (Acreman et al. 2009). Richter and Thomas (2007) provide a framework for the assessment of potential benefits that can be restored through dam re-operation. Effective strategies for dam re-operation also have to include the distribution and usage of benefits from dam operation as well as socio-political and economic drivers. They suggest the inclusion of stakeholders in the setting of specific and short-term goals for water management as well as dam re-operation. However, dam re-operation is not possible in all cases as environmental flows are just one aspect of dam regulations, and redesign can reduce profitability of other services (Dyson et al. 2003).

Other limiting factors for flow implementation belong to legislative, economic, or social aspects. Holistic methods allow for an interdisciplinary analysis of consequences caused by flow allocation rules (see section 2.1). In particular the sociological dimension as well as governance of environmental flows requires further research. While the aspects of the former is already included in the DRIFT methodology (King et al. 2003), governance of environmental flows mainly deals with economic aspects and instruments. Further details on the governance of environmental flows are given in section 2.4.

Monitoring and revision

Monitoring is an integral step of adaptive management to learn from past actions and thereby iteratively improve measures. An effective monitoring network should reveal unintended and unforeseen trends and thus induce a rethinking and reassessment of implementation strategies and underlying assumptions.

Monitoring of environmental flows has two purposes: first, to control the implementation of flows at several points of a river, and second monitor the achievement of a desired condition, for instance, in respect to ecology, or geomorphology (King and Brown 2006). To assure the effective learning from implementation, suitable hypotheses and indicators for monitoring has to be predefined. As described above in section 2.3.1, the objectives hierarchy and Threshold of Potential Concern (TPC) are methods to find and evaluate operable indicators that are linked to overall management goals (Rogers and Biggs 1999).

Another important task besides the implementation of measures is the definition of knowledge gaps that require further research. The participatory process as well as monitoring can reveal case-specific and practical research needs that guide the work of the scientific community (Acreman and King 2003; Richter et al. 2006).

4) Water Governance

Similar to the topic of environmental flows, simplistic as well as detailed approaches for the analysis of governance regime have been developed. While institutional panaceas devised by simplistic approaches turned out to be not useful or even detrimental (Ostrom, 2007;

Ingram, 2008), detailed analyzes are too resource intensive to be applied on a case-by-case basis, and make generalizations difficult. Thus, a diagnostic and systemic approach of intermediate complexity is more promising for the analysis of resource governance systems to allow for transfer of findings across cases (Pahl-Wostl 1995; Ostrom 2007; Young 2007). Applications of this approach have been realized for resource governance (Ostrom 2007; Young 2008) as well as more specifically for water governance regimes (Pahl-Wostl 2009).

Research on governance of environmental flows from a more general, rather than context-sensitive, perspective is lacking. Legislative requirements for the consideration and implementation of environmental flows are diverse around the globe. Research on the implementation of environmental flows in legislation already exists but is restricted to specific pieces of legislation like the EU Water Framework Directive (Acreman et al.2009; Acreman and Ferguson 2010). Water markets are an often promoted solution to achieve efficient water allocation and redistribution of water. Different forms of water markets exist that are open markets, spot markets, administrative water trading, and informal water markets (Le Quesne et al. 2007). Australia has often been referred to as an example for the network mode of governance even though market and hierarchical elements are important aspects in Australian water governance as well (Bell and Park 2006; Bell and Quiggin 2008). Due to the interplay of all governance modes, research on governance of environmental flows is needed to detect general attributes of effective governance regimes and learn from the comparative analysis.

5) Summary

This application area report focuses on management tools for the implementation of environmental flows. Scientific knowledge on environmental flows for individual cases has been determined to be quite developed while the implementation runs far behind (O'Keefe and Le Quesne 2009). Nevertheless, gaps in scientific knowledge exist; there is a lack of knowledge about the fresh water status, quantitative knowledge about flow-ecology links, as well as quantitative knowledge on the importance of freshwater ecosystem services for human livelihood.

Furthermore substantial research is still needed in relation to the implementation of environmental flows in water management. More generic and large scale methods are needed to cope with the increasing pressure on freshwater ecosystems. In this respect, the ELOHA-framework from Poff et al. (2010) is an innovative approach by developing river typologies that can be applied for regional or national flow assessment. In addition, it is important to develop holistic methods like the DRIFT methodology to assess social, economic and environmental consequences of flow alteration, and allow for the balancing of trade-offs (King et al., 2003). This represents an integrative approach which however requires further development, for instance in respect to the consideration of a broader set of social aspects. Adaptive management approaches are required to ensure timely implementation of environmental flows and deal constructively with incomplete knowledge and data about flow-ecology linkages. First frameworks for adaptive management processes have already been developed but these need to be linked to general water resource management processes and concepts like integrated and adaptive water resources management to set environmental flows higher on the water management agenda.

Additionally, further research and testing of participatory methods and tools will be required to assess consequences of flow alteration and related ecosystem services and risks. Participatory approaches help to increase commitment to flow rules, develop holistic strategies to coordinate measures and engagement of actors, and allow for social judgement on ecosystem services. With regard to the design and operation of technical infrastructure innovative approaches must be developed that consider flow rules to overcome impediments to the implementation of environmental flows in case of modified rivers and related wetlands.

Again integrative strategic approaches are needed that combine these technical aspects with economic and social measures.

Finally, water governance is another aspect that requires further research. Several institutional barriers to flow reallocation were identified, such as unclear property rights, high political and economic costs, weak institutional capacity, and existing water management legislation. The analysis of barriers to and drivers of environmental flow implementation in governance regimes is thus an important research topic.

4. Synthesis: Future research needs and recommendations for future research programs

Based on the results of the literature reviews future research needs are assessed in relation to knowledge gaps, science-policy interplay, the relevance of the problem, and the suitability to be implemented in the German scientific community.

4.1 Gaps in scientific knowledge and potential to achieve scientific breakthrough

The literature reviews underline the relevance of each of the four Application Areas on its own but already have revealed some significant research gaps which were summarized at the end of each Application Area chapter.

While each Application Area has its own priorities and varying future research needs, it becomes apparent that the different areas are closely intertwined and cannot be looked at separately. In all four Application Areas the need for improving the knowledge base in relation to various ecological processes is highlighted. It has become apparent that the understanding of these highly complex processes forms an important basis for developing appropriate management approaches and plays a vital role not only in better understanding the functional linkages of natural and technical aquatic ecosystems but also the social-ecological linkages. This forms an important basis for developing appropriate management approaches. For the latter the role of governance regimes must also be explored further in order to arrive at sustainable management solutions balancing human and natural water demands.

Furthermore it was pointed out across the Application Areas that research must expand beyond individual system compartments or simple cause and effect relations to better grasp the complexity of the dynamics in the natural, as well as the social and technical systems across spatial and temporal scales. Monitoring is an important aspect in this context. As the empirical data collected are very site- and context specific methods of transferring results to other regions or scales must be developed.

The research gaps detected in the Application Area reports show the interdisciplinary character of this Theme Cluster. Detailed knowledge is required from the natural, engineering and social sciences for the purposeful manipulation of flow and water bodies to restore, maintain and expand ecosystem services. In this respect, the ‘Environmental Flow’ concept is a suitable approach to link hydrological characteristics of river flows to riverine ecosystem and services they provide. This concept is also applied for the design and management of technical infrastructure like dams and weirs to mimic the flow regime of rivers. Thus, ‘environmental flows’ is an approach that allows the integration of disciplinary knowledge and topics that have been stated in this Theme Cluster.

A quantitative literature research has been conducted for each Application Area using the Scopus citation database of research literature and quality web sources. The analysis explores the development of publications and specific trends in every Application Area for the past 10 years. The results comprise the search terms and number of hits in the title, abstract or keywords in the category “articles and reviews”. The complete results from each Application Area can be found on the CD accompanying this report. Selected findings are presented below.

The human dimension has gained in importance in recent years but the Scopus analyses show that engineering and natural science publications clearly dominate all four Application Areas. An integration of the social science is called for by various authors and emphasis is put on interdisciplinary approaches rather than additional disciplinary research. Further integration is also needed in relation to research approaches within and between the different Application Areas to arrive at a common conceptual basis on which future research can be based.

The number of publications on ‘environmental flows’ increased by nearly five times in the last 10 years, demonstrating the growing importance of environmental flow research (see Table 2). The sub-themes participatory and adaptive management, and flow implementation show an increasing tendency, too. The number of publications for the term ‘environmental flow’ quadrupled, while participatory approaches increased from zero in 1999 to 10 publications in 2009 (see Table 2). Publications on management or implementation of environmental flows have even increased by the factor 40. The links of ecosystem services and governance to environmental flows have had minor relevance in scientific publications during this time frame despite the special importance of these topics (cf. chapters 3.3 and 3.4).

Table 2: Quantitative Scopus analysis (1999-2010)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
„Environmental Flow“	16	17	24	17	40	22	45	47	43	71	68	31
„Environmental Flow“ AND participation OR stakeholder OR communities	0	2	1	2	8	4	4	5	4	10	10	8
„Environmental Flow“ AND adaptive OR adaptation	1	0	0	3	3	0	1	2	2	2	2	7
“Environmental flow” AND implementation OR management	1	3	8	9	20	11	20	22	13	34	40	19
“Environmental flow” AND “ecosystem service”	0	0	0	0	0	0	0	0	0	2	0	2
"Environmental flow" AND governance	0	0	0	0	0	0	3	0	0	0	1	0

Relate to base year = Base year Factor
Number of publications (choice for search space “article or review”) with “Search term” in title, abstract or key words:
Base Year = 1999

The high relevance of environmental flows in research and practice is reflected in the program of major scientific and political conferences on water. At the World Water Week 2009 in Stockholm, two seminars and one workshop were explicitly related to environmental flows implementation as well as the linkage to sustainable development, poverty alleviation, biodiversity conservation, and integrated water resources management. ‘Environmental flows’ also has been a prominent topic at the World Water Forum 2009 in Istanbul. It was raised in two out of six thematic areas as well as the political process. Integrated approaches for flow assessment have been discussed at the World Water Forum including stakeholder participation in the investigation, valuation and management of multiple use and functions of water services. Other important topics have been flow indicators, and environmental flows as a central measure to balance human and ecological needs.

Due to the high political and scientific relevance of environmental flows, large international programs on environmental flow assessment and implementation exist. Research initiatives are conducted by the International Union for Conservation of Nature (IUCN), the International Water management Institute (IWMI), and the International Hydrological Programme (IHP) of the UNESCO. On the national level, the Swedish Environmental Flows Initiative reflects the importance of the concept for national water practice and research (Forslund et al. 2009).

As highlighted at the World Water Forum 2009, an interdisciplinary approach is needed to study the interplay between terrestrial ecosystems, landscapes and the water cycle, as well as operationalization of the findings of this research for policy and management on national and local scales. Research on environmental flows is needed that combines knowledge from the natural sciences with those from social and technical disciplines. This will improve the ability of holistic assessment of flow rules and detection of integrated strategies for implementation in an IWRM framework.

Altogether, the challenges placed upon future research are considerable, but surmountable with good potential to address the gaps successfully building upon existing research. Especially, the concept of "Environmental flows" is suitable to embrace all the distinct research fields stated in the Application Areas. Thus, a future research program should include this integrative concept that is also highly relevant for prevailing social and political issues.

4.2 Science – policy interplay

The overall theme of manipulating flow and water bodies for managing ecosystem services with its four major Application Areas is of high relevance to multiple stakeholder groups at all levels. These include governmental agencies and water managers that are in charge of water resource management or environmental protection. Water user groups have a similar interest in the topic as the allocation of water for environmental flows can have effects on the water availability for other uses. For instance, environmental flows can have a limiting effect on economic activities (e.g. reduced quantities for irrigation in agricultural sector) as well as supportive effects (e.g. habitat for commercial fish). The general public needs to be included in the valuation of ecosystem services and the evaluation of risks that come along with deviations from the natural flow regime of the river.

Since water plays a key role in the landscape system (Falkenmark and Mikulski 1994), the management of environmental flows must be an integral aspect of river basin management and landscape planning. Impacts of global change, like increased exposure to floods and droughts, are predominantly linked to the water system (Lehner et al. 2006; Smith and Barchiesi 2009). Thus, the concept of environmental flows can support the management of complex landscape ecosystems by providing a key variable that influences ecologic processes at large scales. In this respect, Dyson et al. (2003) suggest the recognition and usage of environmental flows as a water resources management tool. Regional environmental flow standards could be developed and integrated into the implementation of the EU Water Framework Directive. Even though environmental flows are not stated explicitly in the directive, it is accepted that the hydrological regime is central for achieving a good status for all water bodies (Acreman and Ferguson 2010). The Water Framework Directive constitutes an innovative piece of water legislation, and thus, provides a unique context to apply research on environmental flows combined with empirical analysis and participatory processes in European river basins. In addition to river conservation, river restoration processes, for instance for heavily modified water bodies, need to consider environmental flows to be effective. The concept of environmental flows particularly facilitates the design and implementation of concerted technological, social and economic measures for the achievement of a good ecological status. In general, the assessment and implementation of environmental flows are urgent tasks for various freshwater ecosystems around the world. Straightening of river beds and construction of impoundments have been realized in many river basins around the globe. This caused degradation of riverine ecosystems and related ecosystem services (WCD 2000).

At the international level particularly the significance of ecosystem services has already been recognized, which is reflected in the establishment of the UNEP ad hoc intergovernmental and multi-stakeholder group which addresses the intergovernmental science-policy interface on biodiversity and ecosystem services. The group has already met twice in 2008 and 2009 - the last meeting will take place in June 2010 - and agreed on the aims to find ways of improving the science-policy interface for biodiversity and ecosystem services across all spatial scales to form a basis for achieving human well-being and sustainable development: "*There is growing consensus that strengthening the interrelations between science and policy at all levels is necessary (but not sufficient) for more effective* *governance of biodiversity and ecosystem services. Current environmental problems, often of considerable magnitude and complexity, challenge science, politics, policy and their interrelations in unprecedented ways, confronting them with situations in which facts are uncertain, values in dispute, stakes high and decisions urgent*." (UNEP/IPBES/2/2 published 2009)

Ways to cooperate and share knowledge and experiences must be developed at all levels. Short and simplified communication channels enabling direct informal exchange without the constraints of formal institutional structures could offer progress in relation to this. For future research programs it may be advisable to make the policy-science interface an integral part of projects where needed and foster cooperation and exchange throughout the duration of the research program making it a learning experience for all involved.

4.3 Relevance of international policy

Ecological, morphological and biological degradation of rivers are major problems of increasing severity. Climate change is likely to lead to thermal and hydrological changes that aggravate the situation in many of the world's river basins (Malmqvist and Rundle 2002) while instantaneously global water demand for society and economy is expected to increase (UNEP 2007).

Specifically urban water systems are characterized by severe changes of natural conditions and fluxes of water, by large-scale technical systems of water capture, treatment, storage and distribution as well as waste and runoff collection, purification and discharge to the receiving water bodies. Surface and ground waters are usually heavily modified in their quality and their function. Downstream water users and the aquatic environment are thus suffering severely from the impact of urban water systems, especially in semi-arid and arid regions. In view of expected trends in demography (decreasing and aging population) in Germany and of climate change and its consequences on the hydrological regime, the urban water systems appear quite vulnerable and need preventive research and adapted management actions. However, our knowledge on the fundamental processes in urban waters is still limited and not sufficient to predict the consequences of different scenarios for cities with various conditions.

The need to find innovative ways to satisfy human demands and protect the functioning of ecosystems and related services at the same time is evident. Forslund et al. (2009) highlight the important role of environmental flows in climate adaptation strategies. As a reaction to these problems, many water legislations around the world demand protection and improvement of riverine ecosystems, and a key role of stakeholder involvement in this process. In most of the cases, environmental flows are not stated explicitly in the national water legislations. Examples for the specification of approaches for the management of environmental flows are the definition of minimum flows in the Swiss Water Protection Act, regulated management for the provision of environmental benefits in the Australian Murray Darling Basin, and statutory management plans that demand a requirement for environmental flows in the South Australian Water Resources Act. The South African Water Act applies a combination of the techniques mentioned above to allocate water for ecosystems (Dyson et al. 2003). From a social perspective, environmental flows are important policy instruments for poverty alleviation (e.g. King et al. 2003) and achievement of the Millennium Development Goals (Forslund et al. 2009).

Focusing on ecosystem services Carpenter et al (2009) point out how some existing policies and practices aimed at achieving win-win situations benefiting both humans and nature, lack a sound knowledge base and are instead based on untested assumptions. Consequently, Carpenter et al (2009) emphasize that it is "imperative for the policy and science communities [to] establish a capacity to create and implement policies for social-ecological systems, predict consequences, and evaluate outcomes". Furthermore it must be borne in mind that different policies and actions are needed at different levels (Zehnder 2010).

Science must assist policy-makers in identifying what kind of policies and tasks are required at the regional, national or international level. Scientific findings must be operationalized and communicated appropriately. For policy-makers it is important to acknowledge human dependence on intact ecosystem services and explicitly integrate environmental water needs into their policies, especially where the flow regimes vary and where the water needs are linked to water quantity and quality (Baron et al 2002). As the ecological and social system are deeply intertwined understanding the underlying processes and dynamics, also in relation to the hydro-ecological linkages, is crucial for policy makers to be able to make informed decisions.

4.4 Suitability of the program to be implemented in the German scientific community

Following the results from this Theme Cluster, the development and integration of knowledge from environmental engineering, hydrology, water governance, and participatory and adaptive water management through research on “environmental flows” is considered to be important to find effective and sustainable approaches for water management. In this section, the suitability of research on environmental flows for the German research community is analyzed.

When it comes to the application of environmental flow methodologies, the USA runs far ahead of other countries. Tharme (2003) counted the application of 77 methodologies in the USA that reflects the high priority and long history of environmental flow assessments. Australia (37), the UK (23), Canada (22), South Africa (20), and New Zealand (20) are in a leading position as well (Tharme 2003). However, all reported cases in Europe add up to 122, demonstrating the importance and relevance of environmental flow methodologies in Europe. Germany with 8 published applications resides in the European average (own calculations based on Tharme 2003).

An analysis of scientific publications has been conducted on research fields that were determined to be most important for the implementation of environmental flows. In this analysis, the nationality of authors’ affiliations of detected publications was determined from the ISI Web-of-Science database to examine the strengths of national research communities in the research fields of hydrological sciences, water governance, participatory water management, adaptive water management, and environmental flows. Table 3 shows the results that demonstrate an excellent position in the top-5 for Germany in the field of water governance, participatory approaches and adaptive water management, and also a leading position in hydrological sciences (rank 6). With eight scientific publications, Germany resides in the top-10 of environmental flow research. The gap towards the leading nation Australia is considerable though (124 publications).

Table 3: Number of publications on selected search terms in the ISI Web-of-Science database, ranked by the nationality of authors’ affiliations

Topic		**Hydrological Sciences**	**Water Governance**	**Participatory water Management**	**Adaptive Water Management**	**Environmental Flows**
Search Term(s)		hydrology	water AND governance	water management ANDparticipation	water management AND (adaptive OR adaptation)	"environmental flows"
Rank	1	USA (5,888)	USA (157)	USA (206)	USA (379)	AUSTRALIA (124)
	2	CANADA (1,188)	ENGLAND (93)	ENGLAND (69)	AUSTRALIA (111)	USA (69)
	3	ENGLAND (1,103)	AUSTRALIA (48)	AUSTRALIA (57)	CANADA (93)	ENGLAND (23)
	4	FRANCE (835)	**GERMANY (35)**	**GERMANY (53)**	ENGLAND (84)	CHINA (21)
	5	AUSTRALIA (766)	NETHERLANDS (35)	NETHERLANDS (50)	**GERMANY (80)**	SOUTH AFRICA (15)
	6	**GERMANY (658)**	CANADA (34)	SOUTH AFRICA (40)	NETHERLANDS (65)	CANADA (14)
	7	NETHERLANDS (530)	SOUTH AFRICA (26)	CANADA (38)	FRANCE (44)	NETHERLANDS (10)
	8	CHINA (389)	FRANCE (21)	INDIA (35)	SPAIN (43)	**GERMANY (8)**
	9	ITALY (356)	CHINA (18)	FRANCE (27)	SOUTH AFRICA (36)	FRANCE (7)
	10	SWITZERLAND (287)	SPAIN (18)	CHINA (26)	CHINA (34)	JAPAN (7)

These results show the high potential for the German research community to take a leading position in the field of environmental flows. In particular, collaborations between scientists from water governance, as well as participatory and adaptive water management with the environmental flow research community are promising to secure and strengthen Germany's leading position, and develop innovative approaches for the assessment and implementation of environmental flows.

4.5 Recommendations for a future research program

The overarching 'Environmental Flow' concept provides a suitable framework for a future research program. It has the capacity to integrate the key topics dealt with in the individual Application Areas into a holistic approach. Particular attention should be paid to improving links to the human dimension with a focus on governance research, as well as existing management approaches in particular IWRM and the concept of Adaptive Management.

It is suggested to install integrative and complimentary projects with an overarching synthesis project to contribute to advancing Environmental Flows research with all its facets. This should link into existing efforts, e.g. as laid out in chapter 4.1, to contribute to developing common conceptual and methodological approaches. New and international unique collaboration of leading organizations is necessary to open new possibilities and horizons for future progress in fundamental research and innovations.

Preferably such an international research program would run over several years in order to capture not only spatial but also temporal variability in the driving variable: flow. However, also a sequence of projects building up on each other may be a feasible approach to advance research. This would add valuable knowledge in obtaining a better understanding of freshwater ecosystems, including groundwater, environmental flows, and the associated challenges pointed out in this report.More specifically at a European level and in Germany environmental flows research should also aim at contributing to the implementation of the Water Framework Directive.

Figure 3 depicts a possible structure for a future research programme of the BMBF.

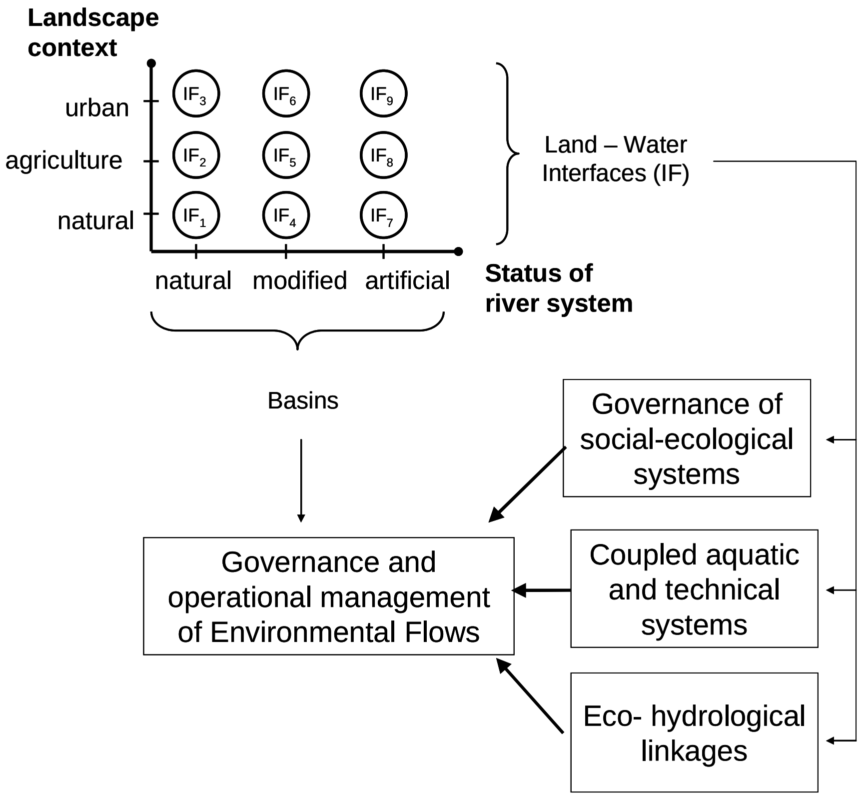

Figure 3: Suggested project structure for a future BMBF research programme that bases on the finding of the Theme Cluster

The topics “Governance of socio-ecological systems”, “Coupled aquatic and technical systems”, and “Eco- hydrological Linkages” presented in figure 3 have been identified to be key challenges of the first three application areas (chapters 3.1 – 3.3). Findings relating to these key topics are then combined under the overall framework of environmental flow research with a special focus on governance and operational management.

The status of river systems can be heterogeneous in respect to their level of modification (i.e. geomorphologic, technical infrastructure), and is closely linked to the adjacent landscape context (cf. chapter 3.1). Thus, research projects focusing on these topics need to consider different land-water interfaces pertaining to the gradients of “status of river system” and the “landscape context”. A suggestion is to develop several case studies at the sub-basin level to produce empirical data called for within in all the aforementioned application areas and develop a common conceptual and methodological research framework by combining the various attributes, as depicted in Figure 3.

Such an integrative approach with a synthesis project allows for the integration of empirical data and theoretical concepts, and provides a basis for identifying opportunities to effectively implement the findings in river-basin management and governance. Thus, the case study level for the integrative approach as a whole should be the entire river basin in order to develop and test approaches for the integrated governance of basins with heterogeneous attributes in respect to the river system and the landscape context.

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Detailed results from literature analysis

The literature analysis was made with the following criteria:

- Search term in title, abstract or key words
- Only records between the period 2000-2010
- Only records that where categorized as either articles and reviews

Analysis includes:

- Country of origin
- Document type
- Publication year
- Source title
- Subject area

Combination of search terms used:

- *“environmental flow” and “ecosystem services”*
- *“flow regime” and “floodplain product*”*
- *“flow regime” and “riparian product*”*
- *“flow regime” and “wetland product*”.*
- *“wetlands” and “carbon sinks”*
- *“wetlands” and “carbon cycling”*
- *“flow” and “carbon cycling”*
- *“discharge” and “carbon cycling”*
- *“flow regime” and “carbon cycling”*
- *“discharge” and “nitrogen cycling”*
- *“flow” and “nitrogen cycling”*
- *“flow regime” and “denitrification”*

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Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

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	AUSTRALIA	5	13.1579 %		
	SWEDEN	5	13.1579 %		
	FRANCE	4	10.5263 %		
	ENGLAND	3	7.8947 %		
	NETHERLANDS	2	5.2632 %		
	SOUTH AFRICA	2	5.2632 %		
	ALBANIA	1	2.6316 %		
	ARGENTINA	1	2.6316 %		
	BOLIVIA	1	2.6316 %		
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→ View Records × Exclude Records	Field: Document Type	Record Count	% of 38	Bar Chart	Save Analysis Data to File
	ARTICLE	34	89.4737 %		
	REVIEW	4	10.5263 %		
→ View Records × Exclude Records	Field: Document Type	Record Count	% of 38	Bar Chart	Save Analysis Data to File

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Analyze Results

38 records. Topic=(environmental flow ecosystem services)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Publication Year	Record Count	% of 38	Bar Chart	Save Analysis Data to File
	2009	11	28.9474 %		
	2008	8	21.0526 %		
	2006	7	18.4211 %		
	2007	3	7.8947 %		
	2010	3	7.8947 %		
	2002	2	5.2632 %		
	2005	2	5.2632 %		
	2001	1	2.6316 %		
	2003	1	2.6316 %		
→ View Records ✕ Exclude Records	Field: Publication Year	Record Count	% of 38	Bar Chart	Save Analysis Data to File

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Analyze Results

38 records. Topic=(environmental flow ecosystem services)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records × Exclude Records	Field: Source Title	Record Count	% of 38	Bar Chart	Save Analysis Data to File
	ECOLOGICAL ECONOMICS	5	13.1579 %		
	ECOLOGICAL APPLICATIONS	2	5.2632 %		
	ECOLOGY AND SOCIETY	2	5.2632 %		
	FOREST ECOLOGY AND MANAGEMENT	2	5.2632 %		
	FRESHWATER BIOLOGY	2	5.2632 %		
	INTERNATIONAL JOURNAL OF SUSTAINABLE DEVELOPMENT AND WORLD ECOLOGY	2	5.2632 %		
	ADVANCES IN AGRONOMY	1	2.6316 %		
	ADVANCES IN AGRONOMY, VOL 98	1	2.6316 %		
	AGRICULTURAL AND FOREST METEOROLOGY	1	2.6316 %		
	AGRICULTURAL WATER MANAGEMENT	1	2.6316 %		
→ View Records × Exclude Records	Field: Source Title	Record Count	% of 38	Bar Chart	Save Analysis Data to File

(20 Source Title value(s) outside display options.)

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Analyze Results

38 records. Topic=(environmental flow ecosystem services)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
× Exclude Records

Save Analysis Data to File

Field: Subject Area	Record Count	% of 38	Bar Chart
ECOLOGY	18	47.3684 %	
ENVIRONMENTAL SCIENCES	16	42.1053 %	
ENVIRONMENTAL STUDIES	9	23.6842 %	
ECONOMICS	6	15.7895 %	
FORESTRY	4	10.5263 %	
MARINE & FRESHWATER BIOLOGY	4	10.5263 %	
AGRONOMY	3	7.8947 %	
WATER RESOURCES	3	7.8947 %	
BIODIVERSITY CONSERVATION	2	5.2632 %	
AGRICULTURAL ECONOMICS & POLICY	1	2.6316 %	
Field: Subject Area	**Record Count**	**% of 38**	**Bar Chart**

→ View Records
× Exclude Records

Save Analysis Data to File

(13 Subject Area value(s) outside display options.)

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Analyze Results

17 records. Topic=(flow regime floodplain product*)
Analysis: Document Type=(ARTICLE)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records × Exclude Records	**Field: Country/Territory**	**Record Count**	**% of 17**	**Bar Chart**	Save Analysis Data to File
	USA	6	35.2941 %		
	AUSTRALIA	5	29.4118 %		
	AUSTRIA	2	11.7647 %		
	BRAZIL	2	11.7647 %		
	ENGLAND	2	11.7647 %		
	CANADA	1	5.8824 %		
	NEW ZEALAND	1	5.8824 %		
	NORWAY	1	5.8824 %		
→ View Records × Exclude Records	**Field: Country/Territory**	**Record Count**	**% of 17**	**Bar Chart**	Save Analysis Data to File

(1 Record (5.8824%)do not contain data in the field being analyzed.)

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Analyze Results

17 records. Topic=(flow regime floodplain product*)
Analysis: Document Type=(ARTICLE)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records / × Exclude Records	Field: Document Type	Record Count	% of 17	Bar Chart	Save Analysis Data to File
	ARTICLE	17	100.0000 %		
→ View Records / × Exclude Records	**Field: Document Type**	**Record Count**	**% of 17**	**Bar Chart**	Save Analysis Data to File

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Analyze Results

17 records. Topic=(flow regime floodplain product*)
Analysis: Document Type=(ARTICLE)

Rank the records by this field:
Author
Conference Title
Country/Territory
Document Type

Analyze: Up to 500 Records.

Set display options: Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:
Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
× Exclude Records

Field: Publication Year	Record Count	% of 17	Bar Chart
2000	3	17.6471 %	
2007	3	17.6471 %	
2008	3	17.6471 %	
2003	2	11.7647 %	
2006	2	11.7647 %	
2010	2	11.7647 %	
2001	1	5.8824 %	
2002	1	5.8824 %	

Save Analysis Data to File

→ View Records
× Exclude Records

Field: Publication Year | Record Count | % of 17 | Bar Chart

Save Analysis Data to File

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Take the next step

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Analyze Results

17 records. Topic=(flow regime floodplain product*)
Analysis: Document Type=(ARTICLE)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
× Exclude Records

Field: Source Title	Record Count	% of 17	Bar Chart	Save Analysis Data to File
FRESHWATER BIOLOGY	2	11.7647 %		
JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION	2	11.7647 %		
ARCHIV FUR HYDROBIOLOGIE	1	5.8824 %		
BIODIVERSITY AND CONSERVATION	1	5.8824 %		
BRAZILIAN JOURNAL OF BIOLOGY	1	5.8824 %		
ECOLOGY AND SOCIETY	1	5.8824 %		
ENVIRONMENTAL MODELLING & SOFTWARE	1	5.8824 %		
FOREST ECOLOGY AND MANAGEMENT	1	5.8824 %		
GEOMORPHOLOGY	1	5.8824 %		
HYDROBIOLOGIA	1	5.8824 %		
Field: Source Title	**Record Count**	**% of 17**	**Bar Chart**	Save Analysis Data to File

→ View Records
× Exclude Records

(5 Source Title value(s) outside display options.)

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Take the next step

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Analyze Results

17 records. Topic=(flow regime floodplain product*)
Analysis: Document Type=(ARTICLE)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Subject Area	Record Count	% of 17	Bar Chart	Save Analysis Data to File
	MARINE & FRESHWATER BIOLOGY	5	29.4118 %		
	ECOLOGY	4	23.5294 %		
	WATER RESOURCES	4	23.5294 %		
	ENGINEERING, ENVIRONMENTAL	3	17.6471 %		
	ENVIRONMENTAL SCIENCES	3	17.6471 %		
	GEOSCIENCES, MULTIDISCIPLINARY	3	17.6471 %		
	BIODIVERSITY CONSERVATION	2	11.7647 %		
	BIOLOGY	1	5.8824 %		
	COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIONS	1	5.8824 %		
	FORESTRY	1	5.8824 %		
→ View Records ✕ Exclude Records	Field: Subject Area	Record Count	% of 17	Bar Chart	Save Analysis Data to File

(4 Subject Area value(s) outside display options.)

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Analyze Results

93 records. Topic=(wetlands carbon sink)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze: Up to 500 Records.

Set display options: Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:
Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..

Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records X Exclude Records	Field: Country/Territory	Record Count	% of 93	Bar Chart	Save Analysis Data to File
	USA	41	44.0860 %		
	CANADA	17	18.2796 %		
	GERMANY	15	16.1290 %		
	PEOPLES R CHINA	8	8.6022 %		
	SWEDEN	8	8.6022 %		
	ITALY	6	6.4516 %		
	AUSTRALIA	5	5.3763 %		
	DENMARK	5	5.3763 %		
	ENGLAND	5	5.3763 %		
	RUSSIA	5	5.3763 %		
→ View Records X Exclude Records	Field: Country/Territory	Record Count	% of 93	Bar Chart	Save Analysis Data to File

(19 Country/Territory value(s) outside display options.)

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Analyze Results

93 records. Topic=(wetlands carbon sink)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	**Analyze:**	**Set display options:**	**Sort by:**
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	**Field: Document Type**	**Record Count**	**% of 93**	**Bar Chart**	Save Analysis Data to File
	ARTICLE	82	88.1720 %		
	REVIEW	11	11.8280 %		
→ View Records ✕ Exclude Records	**Field: Document Type**	**Record Count**	**% of 93**	**Bar Chart**	Save Analysis Data to File

<<< Back to results list

Analyze Results

93 records. Topic=(wetlands carbon sink)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records / × Exclude Records	Field: Publication Year	Record Count	% of 93	Bar Chart	Save Analysis Data to File
	2008	12	12.9032 %		
	2005	11	11.8280 %		
	2007	11	11.8280 %		
	2009	11	11.8280 %		
	2003	9	9.6774 %		
	2006	9	9.6774 %		
	2000	8	8.6022 %		
	2001	8	8.6022 %		
	2002	5	5.3763 %		
	2004	5	5.3763 %		
→ View Records / × Exclude Records	Field: Publication Year	Record Count	% of 93	Bar Chart	Save Analysis Data to File

(2 Publication Year value(s) outside display options.)

Take the next step

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Analyze Results

93 records. Topic=(wetlands carbon sink)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:
Author
Conference Title
Country/Territory
Document Type

Analyze:
Up to 500 Records.

Set display options:
Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:
Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Source Title	Record Count	% of 93	Bar Chart	Save Analysis Data to File
	GLOBAL BIOGEOCHEMICAL CYCLES	9	9.6774 %		
	GLOBAL CHANGE BIOLOGY	7	7.5269 %		
	SCIENCE OF THE TOTAL ENVIRONMENT	6	6.4516 %		
	BIOGEOCHEMISTRY	5	5.3763 %		
	WETLANDS	4	4.3011 %		
	BIOGEOSCIENCES	3	3.2258 %		
	CHEMOSPHERE	3	3.2258 %		
	AQUATIC BOTANY	2	2.1505 %		
	ATMOSPHERIC ENVIRONMENT	2	2.1505 %		
	ECOLOGICAL ENGINEERING	2	2.1505 %		
→ View Records ✕ Exclude Records	Field: Source Title	Record Count	% of 93	Bar Chart	Save Analysis Data to File

(44 Source Title value(s) outside display options.)

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Analyze Results

93 records. Topic=(wetlands carbon sink)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..

Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
X Exclude Records

Field: Subject Area	Record Count	% of 93	Bar Chart
ENVIRONMENTAL SCIENCES	55	59.1398 %	
ECOLOGY	25	26.8817 %	
GEOSCIENCES, MULTIDISCIPLINARY	23	24.7312 %	
METEOROLOGY & ATMOSPHERIC SCIENCES	20	21.5054 %	
BIODIVERSITY CONSERVATION	7	7.5269 %	
ENGINEERING, ENVIRONMENTAL	7	7.5269 %	
SOIL SCIENCE	6	6.4516 %	
PLANT SCIENCES	5	5.3763 %	
WATER RESOURCES	5	5.3763 %	
GEOGRAPHY, PHYSICAL	4	4.3011 %	
Field: Subject Area	**Record Count**	**% of 93**	**Bar Chart**

Save Analysis Data to File

→ View Records
X Exclude Records

Save Analysis Data to File

(14 Subject Area value(s) outside display options.)

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Analyze Results

18 records. Topic=(flow regime carbon cycling)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 250 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

View Records / Exclude Records	Field: Country/Territory	Record Count	% of 18	Bar Chart	Save Analysis Data to File
	GERMANY	5	27.7778 %		
	USA	5	27.7778 %		
	AUSTRALIA	4	22.2222 %		
	BERMUDA	1	5.5556 %		
	CANADA	1	5.5556 %		
	ECUADOR	1	5.5556 %		
	ESTONIA	1	5.5556 %		
	ITALY	1	5.5556 %		
	NORWAY	1	5.5556 %		
	PEOPLES R CHINA	1	5.5556 %		
	SCOTLAND	1	5.5556 %		
	SOUTH AFRICA	1	5.5556 %		
View Records / Exclude Records	Field: Country/Territory	Record Count	% of 18	Bar Chart	Save Analysis Data to File

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Take the next step

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Analyze Results

18 records. Topic=(flow regime carbon cycling)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 250 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records X Exclude Records	Field: Document Type	Record Count	% of 18	Bar Chart	Save Analysis Data to File
	ARTICLE	14	77.7778 %		
	REVIEW	4	22.2222 %		
→ View Records X Exclude Records	**Field: Document Type**	**Record Count**	**% of 18**	**Bar Chart**	Save Analysis Data to File

Please give us your feedback on using ISI Web Of Knowledge

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Analyze Results

18 records. Topic=(flow regime carbon cycling)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze: Up to 500 Records.

Set display options: Show the top 250 Results.
Minimum record count (Threshold): 0

Sort by:
Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records / X Exclude Records	Field: Publication Year	Record Count	% of 18	Bar Chart	Save Analysis Data to File
	2006	4	22.2222 %		
	2007	4	22.2222 %		
	2004	2	11.1111 %		
	2005	2	11.1111 %		
	1992	1	5.5556 %		
	1996	1	5.5556 %		
	1999	1	5.5556 %		
	2002	1	5.5556 %		
	2008	1	5.5556 %		
	2009	1	5.5556 %		
→ View Records / X Exclude Records	Field: Publication Year	Record Count	% of 18	Bar Chart	Save Analysis Data to File

<<< Back to results list

Analyze Results

18 records. Topic=(flow regime carbon cycling)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:
Author
Conference Title
Country/Territory
Document Type

Analyze:
Up to 500 Records.

Set display options:
Show the top 250 Results.
Minimum record count (Threshold): 0

Sort by:
Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
✕ Exclude Records

Field: Source Title	Record Count	% of 18	Bar Chart
AGRICULTURAL WATER MANAGEMENT	1	5.5556 %	
AGRICULTURE ECOSYSTEMS & ENVIRONMENT	1	5.5556 %	
AQUATIC BOTANY	1	5.5556 %	
BIOGEOCHEMISTRY	1	5.5556 %	
BOREAL ENVIRONMENT RESEARCH	1	5.5556 %	
CHINESE SCIENCE BULLETIN	1	5.5556 %	
CLIMATE RESEARCH	1	5.5556 %	
DEEP-SEA RESEARCH PART I-OCEANOGRAPHIC RESEARCH PAPERS	1	5.5556 %	
ECOLOGICAL APPLICATIONS	1	5.5556 %	
JOURNAL OF GEOPHYSICAL RESEARCH-BIOGEOSCIENCES	1	5.5556 %	
JOURNAL OF GEOPHYSICAL RESEARCH-OCEANS	1	5.5556 %	
MARINE CHEMISTRY	1	5.5556 %	
MINERALIUM DEPOSITA	1	5.5556 %	
NEW PHYTOLOGIST	1	5.5556 %	
POLAR BIOLOGY	1	5.5556 %	
QUATERNARY SCIENCE REVIEWS	1	5.5556 %	
RIVER RESEARCH AND APPLICATIONS	1	5.5556 %	
WATER SA	1	5.5556 %	

Save Analysis Data to File

→ View Records
✕ Exclude Records

Field: Source Title | Record Count | % of 18 | Bar Chart

Save Analysis Data to File

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Take the next step

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Analyze Results

18 records. Topic=(flow regime carbon cycling)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 250 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Subject Area	Record Count	% of 18	Bar Chart	Save Analysis Data to File
	ENVIRONMENTAL SCIENCES	7	38.8889 %		
	ECOLOGY	3	16.6667 %		
	GEOSCIENCES, MULTIDISCIPLINARY	3	16.6667 %		
	OCEANOGRAPHY	3	16.6667 %		
	WATER RESOURCES	3	16.6667 %		
	PLANT SCIENCES	2	11.1111 %		
	AGRICULTURE, MULTIDISCIPLINARY	1	5.5556 %		
	AGRONOMY	1	5.5556 %		
	BIODIVERSITY CONSERVATION	1	5.5556 %		
	CHEMISTRY, MULTIDISCIPLINARY	1	5.5556 %		
	GEOCHEMISTRY & GEOPHYSICS	1	5.5556 %		
	GEOGRAPHY, PHYSICAL	1	5.5556 %		
	MARINE & FRESHWATER BIOLOGY	1	5.5556 %		
	METEOROLOGY & ATMOSPHERIC SCIENCES	1	5.5556 %		
	MINERALOGY	1	5.5556 %		
	MULTIDISCIPLINARY SCIENCES	1	5.5556 %		
→ View Records ✕ Exclude Records	Field: Subject Area	Record Count	% of 18	Bar Chart	Save Analysis Data to File

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Analyze Results

162 records. Topic=(flow carbon cycling)
Analysis: Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY) AND Document Type=(ARTICLE OR REVIEW) AND Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY)

Rank the records by this field: Author, Conference Title, Country/Territory, Document Type

Analyze: Up to 500 Records.

Set display options: Show the top 250 Results. Minimum record count (Threshold): 2

Sort by: Record count / Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
X Exclude Records

Field: Country/Territory	Record Count	% of 162	Bar Chart
USA	86	53.0864 %	
GERMANY	18	11.1111 %	
CANADA	16	9.8765 %	
AUSTRALIA	13	8.0247 %	
FRANCE	9	5.5556 %	
DENMARK	8	4.9383 %	
ENGLAND	7	4.3210 %	
JAPAN	7	4.3210 %	
ITALY	6	3.7037 %	
NEW ZEALAND	6	3.7037 %	
PEOPLES R CHINA	6	3.7037 %	
SPAIN	6	3.7037 %	
SCOTLAND	5	3.0864 %	
NETHERLANDS	4	2.4691 %	
SOUTH AFRICA	4	2.4691 %	
SWEDEN	4	2.4691 %	
SWITZERLAND	4	2.4691 %	
WALES	3	1.8519 %	
AUSTRIA	2	1.2346 %	
BELGIUM	2	1.2346 %	
CHILE	2	1.2346 %	
NORWAY	2	1.2346 %	

Save Analysis Data to File

→ View Records
X Exclude Records
Field: Country/Territory Record Count % of 162 Bar Chart Save Analysis Data to File

(16 Country/Territory value(s) outside display options.)

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Analyze Results

162 records. Topic=(flow carbon cycling)
Analysis: Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY) AND Document Type=(ARTICLE OR REVIEW) AND Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY)

Rank the records by this field:	**Analyze:**	**Set display options:**	**Sort by:**
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 250 Results. Minimum record count (Threshold): 2	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

View Records / Exclude Records	**Field: Document Type**	**Record Count**	**% of 162**	**Bar Chart**	Save Analysis Data to File
	ARTICLE	143	88.2716 %		
	REVIEW	19	11.7284 %		
View Records / Exclude Records	**Field: Document Type**	**Record Count**	**% of 162**	**Bar Chart**	Save Analysis Data to File

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Analyze Results

162 records. Topic=(flow carbon cycling)
Analysis: Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY) AND Document Type=(ARTICLE OR REVIEW) AND Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 250 Results. Minimum record count (Threshold): 2	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Publication Year	Record Count	% of 162	Bar Chart	Save Analysis Data to File
	2009	22	13.5802 %		
	2006	21	12.9630 %		
	2005	18	11.1111 %		
	2000	16	9.8765 %		
	2004	16	9.8765 %		
	2007	16	9.8765 %		
	2008	16	9.8765 %		
	2003	13	8.0247 %		
	2002	11	6.7901 %		
	2001	9	5.5556 %		
	2010	4	2.4691 %		
→ View Records ✕ Exclude Records	**Field: Publication Year**	**Record Count**	**% of 162**	**Bar Chart**	Save Analysis Data to File

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Analyze Results

162 records. Topic=(flow carbon cycling)
Analysis: Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY) AND Document Type=(ARTICLE OR REVIEW) AND Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY)

Rank the records by this field:	**Analyze:**	**Set display options:**	**Sort by:**
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 250 Results. Minimum record count (Threshold): 2	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
✕ Exclude Records

Save Analysis Data to File

Field: Source Title	Record Count	% of 162	Bar Chart
MARINE ECOLOGY-PROGRESS SERIES	13	8.0247 %	
ECOLOGY	10	6.1728 %	
AQUATIC MICROBIAL ECOLOGY	9	5.5556 %	
ECOLOGICAL MODELLING	6	3.7037 %	
GLOBAL CHANGE BIOLOGY	6	3.7037 %	
JOURNAL OF GEOPHYSICAL RESEARCH-BIOGEOSCIENCES	6	3.7037 %	
BIOGEOCHEMISTRY	5	3.0864 %	
ECOSYSTEMS	4	2.4691 %	
ESTUARINE COASTAL AND SHELF SCIENCE	4	2.4691 %	
FRESHWATER BIOLOGY	4	2.4691 %	
GLOBAL BIOGEOCHEMICAL CYCLES	4	2.4691 %	
OECOLOGIA	4	2.4691 %	
WATER RESOURCES RESEARCH	4	2.4691 %	
ARCTIC ANTARCTIC AND ALPINE RESEARCH	3	1.8519 %	
BIOGEOSCIENCES	3	1.8519 %	
ECOLOGICAL APPLICATIONS	3	1.8519 %	
HYDROBIOLOGIA	3	1.8519 %	
MICROBIAL ECOLOGY	3	1.8519 %	
AQUATIC BOTANY	2	1.2346 %	
AQUATIC SCIENCES	2	1.2346 %	
ECOLOGICAL ENGINEERING	2	1.2346 %	
ENVIRONMENTAL			

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Analyze Results

162 records. Topic=(flow carbon cycling)
Analysis: Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY) AND Document Type=(ARTICLE OR REVIEW) AND Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 250 Results. Minimum record count (Threshold): 2	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Subject Area	Record Count	% of 162	Bar Chart	Save Analysis Data to File
	ECOLOGY	80	49.3827 %		
	ENVIRONMENTAL SCIENCES	61	37.6543 %		
	MARINE & FRESHWATER BIOLOGY	60	37.0370 %		
	GEOSCIENCES, MULTIDISCIPLINARY	31	19.1358 %		
	OCEANOGRAPHY	23	14.1975 %		
	WATER RESOURCES	13	8.0247 %		
	LIMNOLOGY	12	7.4074 %		
	MICROBIOLOGY	12	7.4074 %		
	BIODIVERSITY CONSERVATION	9	5.5556 %		
	ENGINEERING, ENVIRONMENTAL	8	4.9383 %		
	GEOGRAPHY, PHYSICAL	7	4.3210 %		
	METEOROLOGY & ATMOSPHERIC SCIENCES	6	3.7037 %		
	ENGINEERING, CIVIL	3	1.8519 %		
	PLANT SCIENCES	3	1.8519 %		
	EVOLUTIONARY BIOLOGY	2	1.2346 %		
	FISHERIES	2	1.2346 %		
→ View Records ✕ Exclude Records	Field: Subject Area	Record Count	% of 162	Bar Chart	Save Analysis Data to File

(7 Subject Area value(s) outside display options.)

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Analyze Results

58 records. Topic=(discharge carbon cycling)
Analysis: Subject Areas=(ECOLOGY OR LIMNOLOGY OR ENVIRONMENTAL SCIENCES OR GEOSCIENCES, MULTIDISCIPLINARY OR MARINE & FRESHWATER BIOLOGY OR WATER RESOURCES) AND Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:
Author
Conference Title
Country/Territory
Document Type

Analyze: Up to 500 Records.

Set display options: Show the top 100 Results.
Minimum record count (Threshold): 0

Sort by:
Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count
if the original set contained more records than the number of records analyzed.

→ View Records
✕ Exclude Records

Field: Subject Area	Record Count	% of 58	Bar Chart
ENVIRONMENTAL SCIENCES	29	50.0000 %	
GEOSCIENCES, MULTIDISCIPLINARY	26	44.8276 %	
MARINE & FRESHWATER BIOLOGY	12	20.6897 %	
WATER RESOURCES	10	17.2414 %	
ECOLOGY	7	12.0690 %	
LIMNOLOGY	6	10.3448 %	
OCEANOGRAPHY	6	10.3448 %	
METEOROLOGY & ATMOSPHERIC SCIENCES	5	8.6207 %	
ENERGY & FUELS	4	6.8966 %	
CHEMISTRY, PHYSICAL	3	5.1724 %	
PHYSICS, ATOMIC, MOLECULAR & CHEMICAL	3	5.1724 %	
ENGINEERING, CIVIL	2	3.4483 %	
BIOCHEMISTRY & MOLECULAR BIOLOGY	1	1.7241 %	
CHEMISTRY, MULTIDISCIPLINARY	1	1.7241 %	
ENGINEERING, CHEMICAL	1	1.7241 %	
GEOGRAPHY, PHYSICAL	1	1.7241 %	
SOIL SCIENCE	1	1.7241 %	
TOXICOLOGY	1	1.7241 %	

Save Analysis Data to File

→ View Records
✕ Exclude Records

Field: Subject Area	Record Count	% of 58	Bar Chart

Save Analysis Data to File

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Analyze Results

58 records. Topic=(discharge carbon cycling)
Analysis: Subject Areas=(ECOLOGY OR LIMNOLOGY OR ENVIRONMENTAL SCIENCES OR GEOSCIENCES, MULTIDISCIPLINARY OR MARINE & FRESHWATER BIOLOGY OR WATER RESOURCES) AND Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	**Analyze:**	**Set display options:**	**Sort by:**
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 100 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
✕ Exclude Records

Field: Source Title	Record Count	% of 58	Bar Chart	Save Analysis Data to File
JOURNAL OF GEOPHYSICAL RESEARCH-BIOGEOSCIENCES	7	12.0690 %		
BIOGEOCHEMISTRY	6	10.3448 %		
GLOBAL BIOGEOCHEMICAL CYCLES	5	8.6207 %		
HYDROLOGICAL PROCESSES	5	8.6207 %		
ESTUARINE COASTAL AND SHELF SCIENCE	3	5.1724 %		
FRESHWATER BIOLOGY	3	5.1724 %		
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY	3	5.1724 %		
ECOLOGY	2	3.4483 %		
GEOPHYSICAL RESEARCH LETTERS	2	3.4483 %		
JOURNAL OF HYDROLOGY	2	3.4483 %		
WATER RESOURCES RESEARCH	2	3.4483 %		
AQUATIC SCIENCES	1	1.7241 %		
CHEMISTRY AND ECOLOGY	1	1.7241 %		
ECOLOGICAL RESEARCH	1	1.7241 %		
ECOSYSTEMS	1	1.7241 %		
ENERGY & ENVIRONMENTAL SCIENCE	1	1.7241 %		
ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH	1	1.7241 %		
FUNDAMENTAL AND APPLIED LIMNOLOGY	1	1.7241 %		
HYDROBIOLOGIA	1	1.7241 %		
HYDROLOGY AND EARTH SYSTEM SCIENCES	1	1.7241 %		

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Analyze Results

58 records. Topic=(discharge carbon cycling)
Analysis: Subject Areas=(ECOLOGY OR LIMNOLOGY OR ENVIRONMENTAL SCIENCES OR GEOSCIENCES, MULTIDISCIPLINARY OR MARINE & FRESHWATER BIOLOGY OR WATER RESOURCES) AND Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	**Analyze:**	**Set display options:**	**Sort by:**
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 100 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

View Records / Exclude Records	**Field: Publication Year**	**Record Count**	**% of 58**	**Bar Chart**	Save Analysis Data to File
	2009	11	18.9655 %		
	2005	8	13.7931 %		
	2007	8	13.7931 %		
	2008	8	13.7931 %		
	2003	5	8.6207 %		
	2006	5	8.6207 %		
x	2000	4	6.8966 %		
	2002	3	5.1724 %		
	2004	2	3.4483 %		
	2010	2	3.4483 %		
	1999	1	1.7241 %		
	2001	1	1.7241 %		
View Records / Exclude Records	**Field: Publication Year**	**Record Count**	**% of 58**	**Bar Chart**	Save Analysis Data to File

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Analyze Results

58 records. Topic=(discharge carbon cycling)
Analysis: Subject Areas=(ECOLOGY OR LIMNOLOGY OR ENVIRONMENTAL SCIENCES OR GEOSCIENCES, MULTIDISCIPLINARY OR MARINE & FRESHWATER BIOLOGY OR WATER RESOURCES) AND Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 100 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Document Type	Record Count	% of 58	Bar Chart	Save Analysis Data to File
	ARTICLE	55	94.8276 %		
	REVIEW	3	5.1724 %		
→ View Records ✕ Exclude Records	Field: Document Type	Record Count	% of 58	Bar Chart	Save Analysis Data to File

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Analyze Results

58 records. Topic=(discharge carbon cycling)
Analysis: Subject Areas=(ECOLOGY OR LIMNOLOGY OR ENVIRONMENTAL SCIENCES OR GEOSCIENCES, MULTIDISCIPLINARY OR MARINE & FRESHWATER BIOLOGY OR WATER RESOURCES) AND Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	**Analyze:**	**Set display options:**	**Sort by:**
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 100 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count
if the original set contained more records than the number of records analyzed.

→ View Records X Exclude Records	**Field: Country/Territory**	**Record Count**	**% of 58**	**Bar Chart**	Save Analysis Data to File
	USA	32	55.1724 %		
	GERMANY	5	8.6207 %		
	FRANCE	4	6.8966 %		
	AUSTRALIA	3	5.1724 %		
	ENGLAND	3	5.1724 %		
	PEOPLES R CHINA	3	5.1724 %		
	SWITZERLAND	3	5.1724 %		
	BELGIUM	2	3.4483 %		
	BRAZIL	2	3.4483 %		
	CANADA	2	3.4483 %		
	INDIA	2	3.4483 %		
	ITALY	2	3.4483 %		
	JAPAN	2	3.4483 %		
	NETHERLANDS	2	3.4483 %		
	SWEDEN	2	3.4483 %		
	ARGENTINA	1	1.7241 %		
	AUSTRIA	1	1.7241 %		
	ECUADOR	1	1.7241 %		
	FINLAND	1	1.7241 %		
	SINGAPORE	1	1.7241 %		
	SOUTH AFRICA	1	1.7241 %		
	TAIWAN	1	1.7241 %		
→ View Records X Exclude Records	**Field: Country/Territory**	**Record Count**	**% of 58**	**Bar Chart**	Save Analysis Data to File

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Analyze Results

151 records. Topic=(flow nitrogen cycling)
Analysis: Document Type=(ARTICLE OR REVIEW) AND Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY)

Rank the records by this field: Author, Conference Title, Country/Territory, Document Type

Analyze: Up to 500 Records.

Set display options: Show the top 250 Results. Minimum record count (Threshold): 0

Sort by: Record count / Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
✗ Exclude Records

Save Analysis Data to File

Field: Country/Territory	Record Count	% of 151	Bar Chart
USA	92	60.9272 %	
AUSTRALIA	13	8.6093 %	
CANADA	10	6.6225 %	
GERMANY	9	5.9603 %	
FRANCE	8	5.2980 %	
ENGLAND	7	4.6358 %	
PEOPLES R CHINA	7	4.6358 %	
DENMARK	4	2.6490 %	
NETHERLANDS	4	2.6490 %	
NEW ZEALAND	4	2.6490 %	
SCOTLAND	4	2.6490 %	
SWEDEN	4	2.6490 %	
POLAND	3	1.9868 %	
SWITZERLAND	3	1.9868 %	
FINLAND	2	1.3245 %	
GREECE	2	1.3245 %	
ITALY	2	1.3245 %	
JAPAN	2	1.3245 %	
NORWAY	2	1.3245 %	
ROMANIA	2	1.3245 %	
SPAIN	2	1.3245 %	
WALES	2	1.3245 %	
ARGENTINA	1	0.6623 %	
BANGLADESH	1	0.6623 %	
BELGIUM	1	0.6623 %	
BRAZIL	1	0.6623 %	
CZECH REPUBLIC	1	0.6623 %	
ECUADOR	1	0.6623 %	
ESTONIA	1	0.6623 %	
INDIA	1	0.6623 %	
ISRAEL	1	0.6623 %	
SOUTH AFRICA	1	0.6623 %	
TAIWAN	1	0.6623 %	
THAILAND	1	0.6623 %	

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Analyze Results

151 records. Topic=(flow nitrogen cycling)
Analysis: Document Type=(ARTICLE OR REVIEW) AND Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 250 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
X Exclude Records

Field: Publication Year	Record Count	% of 151	Bar Chart
2007	23	15.2318 %	
2008	17	11.2583 %	
2009	17	11.2583 %	
2000	15	9.9338 %	
2003	15	9.9338 %	
2002	13	8.6093 %	
2006	13	8.6093 %	
2004	12	7.9470 %	
2005	12	7.9470 %	
2001	9	5.9603 %	
2010	5	3.3113 %	
Field: Publication Year	**Record Count**	**% of 151**	**Bar Chart**

Save Analysis Data to File

→ View Records
X Exclude Records

Save Analysis Data to File

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Analyze Results

151 records. Topic=(flow nitrogen cycling)
Analysis: Document Type=(ARTICLE OR REVIEW) AND Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 250 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
✕ Exclude Records

Save Analysis Data to File

Field: Source Title	Record Count	% of 151	Bar Chart
ECOLOGY	11	7.2848 %	
BIOGEOCHEMISTRY	8	5.2980 %	
ECOLOGICAL MODELLING	7	4.6358 %	
ESTUARIES	7	4.6358 %	
OECOLOGIA	7	4.6358 %	
JOURNAL OF GEOPHYSICAL RESEARCH-BIOGEOSCIENCES	6	3.9735 %	
AQUATIC MICROBIAL ECOLOGY	4	2.6490 %	
ECOLOGICAL APPLICATIONS	4	2.6490 %	
ECOSYSTEMS	4	2.6490 %	
ESTUARINE COASTAL AND SHELF SCIENCE	4	2.6490 %	
FRESHWATER BIOLOGY	4	2.6490 %	
JOURNAL OF HYDROLOGY	4	2.6490 %	
JOURNAL OF THE NORTH AMERICAN BENTHOLOGICAL SOCIETY	4	2.6490 %	
WATER RESOURCES RESEARCH	4	2.6490 %	
JOURNAL OF ENVIRONMENTAL QUALITY	3	1.9868 %	
JOURNAL OF EXPERIMENTAL MARINE BIOLOGY AND ECOLOGY	3	1.9868 %	
AGRICULTURE ECOSYSTEMS & ENVIRONMENT	2	1.3245 %	
ECOLOGICAL ENGINEERING	2	1.3245 %	
GLOBAL BIOGEOCHEMICAL CYCLES	2	1.3245 %	

TOXICOLOGY AND CHEMISTRY	1	0.6623 %	I
FUNDAMENTAL AND APPLIED LIMNOLOGY	1	0.6623 %	I
GEOPHYSICAL RESEARCH LETTERS	1	0.6623 %	I
GROUND WATER	1	0.6623 %	I
ISME JOURNAL	1	0.6623 %	I
ISOTOPES IN ENVIRONMENTAL AND HEALTH STUDIES	1	0.6623 %	I
JOURNAL OF ARID ENVIRONMENTS	1	0.6623 %	I
JOURNAL OF ECOLOGY	1	0.6623 %	I
JOURNAL OF GREAT LAKES RESEARCH	1	0.6623 %	I
JOURNAL OF PETROLEUM SCIENCE AND ENGINEERING	1	0.6623 %	I
JOURNAL OF PLANKTON RESEARCH	1	0.6623 %	I
JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION	1	0.6623 %	I
LAKE AND RESERVOIR MANAGEMENT	1	0.6623 %	I
MARINE BIOLOGY	1	0.6623 %	I
NEW ZEALAND JOURNAL OF MARINE AND FRESHWATER RESEARCH	1	0.6623 %	I
PROGRESS IN PHYSICAL GEOGRAPHY	1	0.6623 %	I
QUATERNARY SCIENCE REVIEWS	1	0.6623 %	I
RESOURCES CONSERVATION AND RECYCLING	1	0.6623 %	I
SCIENTIA MARINA	1	0.6623 %	I
WATER ENVIRONMENT RESEARCH	1	0.6623 %	I
Field: Source Title	**Record Count**	**% of 151**	**Bar Chart**

→ View Records
✕ Exclude Records

Save Analysis Data to File

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Analyze Results

151 records. Topic=(flow nitrogen cycling)
Analysis: Document Type=(ARTICLE OR REVIEW) AND Subject Areas=(ECOLOGY OR ENVIRONMENTAL SCIENCES OR MARINE & FRESHWATER BIOLOGY OR GEOSCIENCES, MULTIDISCIPLINARY)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 250 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

➔ View Records
✕ Exclude Records

Field: Subject Area	Record Count	% of 151	Bar Chart
ECOLOGY	67	44.3709 %	
ENVIRONMENTAL SCIENCES	66	43.7086 %	
MARINE & FRESHWATER BIOLOGY	45	29.8013 %	
GEOSCIENCES, MULTIDISCIPLINARY	27	17.8808 %	
WATER RESOURCES	17	11.2583 %	
OCEANOGRAPHY	11	7.2848 %	
LIMNOLOGY	10	6.6225 %	
ENGINEERING, ENVIRONMENTAL	9	5.9603 %	
MICROBIOLOGY	7	4.6358 %	
METEOROLOGY & ATMOSPHERIC SCIENCES	5	3.3113 %	
BIODIVERSITY CONSERVATION	4	2.6490 %	
ENGINEERING, CIVIL	4	2.6490 %	
FISHERIES	3	1.9868 %	
GEOGRAPHY, PHYSICAL	3	1.9868 %	
TOXICOLOGY	3	1.9868 %	
AGRICULTURE, MULTIDISCIPLINARY	2	1.3245 %	
EVOLUTIONARY BIOLOGY	2	1.3245 %	
CHEMISTRY, INORGANIC & NUCLEAR	1	0.6623 %	
ENGINEERING, PETROLEUM	1	0.6623 %	
ENVIRONMENTAL STUDIES	1	0.6623 %	
MECHANICS	1	0.6623 %	
PLANT SCIENCES	1	0.6623 %	
SOIL SCIENCE	1	0.6623 %	
Field: Subject Area	Record Count	% of 151	Bar Chart

Save Analysis Data to File

➔ View Records
✕ Exclude Records

Save Analysis Data to File

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Analyze Results

53 records. Topic=(discharge nitrogen cycling)
Analysis: Subject Areas=(ENVIRONMENTAL SCIENCES OR GEOSCIENCES, MULTIDISCIPLINARY OR MARINE & FRESHWATER BIOLOGY OR ECOLOGY) AND Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	**Analyze:**	**Set display options:**	**Sort by:**
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 100 Results. Minimum record count (Threshold): 2	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count
if the original set contained more records than the number of records analyzed.

→ View Records ✗ Exclude Records	**Field: Country/Territory**	**Record Count**	**% of 53**	**Bar Chart**	Save Analysis Data to File
	USA	33	62.2642 %		
	AUSTRALIA	3	5.6604 %		
	BELGIUM	3	5.6604 %		
	ENGLAND	3	5.6604 %		
	GERMANY	3	5.6604 %		
	NETHERLANDS	3	5.6604 %		
	FRANCE	2	3.7736 %		
	SWITZERLAND	2	3.7736 %		
→ View Records ✗ Exclude Records	**Field: Country/Territory**	**Record Count**	**% of 53**	**Bar Chart**	Save Analysis Data to File

(15 Country/Territory value(s) outside display options.)

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Analyze Results

53 records. Topic=(discharge nitrogen cycling)
Analysis: Subject Areas=(ENVIRONMENTAL SCIENCES OR GEOSCIENCES, MULTIDISCIPLINARY OR MARINE & FRESHWATER BIOLOGY OR ECOLOGY) AND Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 100 Results. Minimum record count (Threshold): 2	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count
if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Document Type	Record Count	% of 53	Bar Chart	Save Analysis Data to File
	ARTICLE	50	94.3396 %		
	REVIEW	3	5.6604 %		
→ View Records ✕ Exclude Records	**Field: Document Type**	**Record Count**	**% of 53**	**Bar Chart**	Save Analysis Data to File

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Analyze Results

53 records. Topic=(discharge nitrogen cycling)
Analysis: Subject Areas=(ENVIRONMENTAL SCIENCES OR GEOSCIENCES, MULTIDISCIPLINARY OR MARINE & FRESHWATER BIOLOGY OR ECOLOGY) AND Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 100 Results. Minimum record count (Threshold): 2	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records X Exclude Records	Field: Publication Year	Record Count	% of 53	Bar Chart	Save Analysis Data to File
	2003	8	15.0943 %		
	2005	7	13.2075 %		
	2006	7	13.2075 %		
	2009	7	13.2075 %		
	2000	5	9.4340 %		
	2004	4	7.5472 %		
	2001	3	5.6604 %		
	2002	3	5.6604 %		
	2007	3	5.6604 %		
	2008	3	5.6604 %		
	2010	3	5.6604 %		
→ View Records X Exclude Records	Field: Publication Year	Record Count	% of 53	Bar Chart	Save Analysis Data to File

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Analyze Results

53 records. Topic=(discharge nitrogen cycling)
Analysis: Subject Areas=(ENVIRONMENTAL SCIENCES OR GEOSCIENCES, MULTIDISCIPLINARY OR MARINE & FRESHWATER BIOLOGY OR ECOLOGY) AND Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 100 Results. Minimum record count (Threshold): 2	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Source Title	Record Count	% of 53	Bar Chart	Save Analysis Data to File
	JOURNAL OF GEOPHYSICAL RESEARCH-BIOGEOSCIENCES	6	11.3208 %		
	BIOGEOCHEMISTRY	5	9.4340 %		
	ESTUARINE COASTAL AND SHELF SCIENCE	4	7.5472 %		
	ECOLOGY	3	5.6604 %		
	JOURNAL OF THE NORTH AMERICAN BENTHOLOGICAL SOCIETY	3	5.6604 %		
	AQUACULTURE	2	3.7736 %		
	ECOLOGICAL ENGINEERING	2	3.7736 %		
	ENVIRONMENTAL SCIENCE & TECHNOLOGY	2	3.7736 %		
	GLOBAL BIOGEOCHEMICAL CYCLES	2	3.7736 %		
	JOURNAL OF HYDROLOGY	2	3.7736 %		
	MARINE ECOLOGY-PROGRESS SERIES	2	3.7736 %		
→ View Records ✕ Exclude Records	Field: Source Title	Record Count	% of 53	Bar Chart	Save Analysis Data to File

(20 Source Title value(s) outside display options.)

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Analyze Results

53 records. Topic=(discharge nitrogen cycling)
Analysis: Subject Areas=(ENVIRONMENTAL SCIENCES OR GEOSCIENCES, MULTIDISCIPLINARY OR MARINE & FRESHWATER BIOLOGY OR ECOLOGY) AND Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	**Analyze:**	**Set display options:**	**Sort by:**
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 100 Results. Minimum record count (Threshold): 2	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	**Field: Subject Area**	**Record Count**	**% of 53**	**Bar Chart**	Save Analysis Data to File
	ENVIRONMENTAL SCIENCES	28	52.8302 %		
	GEOSCIENCES, MULTIDISCIPLINARY	19	35.8491 %		
	ECOLOGY	16	30.1887 %		
	MARINE & FRESHWATER BIOLOGY	16	30.1887 %		
	ENGINEERING, ENVIRONMENTAL	6	11.3208 %		
	OCEANOGRAPHY	6	11.3208 %		
	WATER RESOURCES	5	9.4340 %		
	ENGINEERING, CIVIL	2	3.7736 %		
	FISHERIES	2	3.7736 %		
	METEOROLOGY & ATMOSPHERIC SCIENCES	2	3.7736 %		
→ View Records ✕ Exclude Records	**Field: Subject Area**	**Record Count**	**% of 53**	**Bar Chart**	Save Analysis Data to File

(7 Subject Area value(s) outside display options.)

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Analyze Results

16 records. Topic=(flow regime riparian product*)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count
if the original set contained more records than the number of records analyzed.

→ View Records
✗ Exclude Records

Field: Country/Territory	Record Count	% of 16	Bar Chart
USA	10	62.5000 %	
CANADA	2	12.5000 %	
ENGLAND	2	12.5000 %	
SPAIN	2	12.5000 %	
SWITZERLAND	2	12.5000 %	
ARGENTINA	1	6.2500 %	
AUSTRALIA	1	6.2500 %	
BELGIUM	1	6.2500 %	
FRANCE	1	6.2500 %	
GERMANY	1	6.2500 %	

Save Analysis Data to File

→ View Records
✗ Exclude Records

Field: Country/Territory	Record Count	% of 16	Bar Chart

Save Analysis Data to File

(5 Country/Territory value(s) outside display options.)

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Take the next step

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Analyze Results

16 records. Topic=(flow regime riparian product*)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count
if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Document Type	Record Count	% of 16	Bar Chart	Save Analysis Data to File
	ARTICLE	14	87.5000 %		
	REVIEW	2	12.5000 %		
→ View Records ✕ Exclude Records	Field: Document Type	Record Count	% of 16	Bar Chart	Save Analysis Data to File

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Analyze Results

16 records. Topic=(flow regime riparian product*)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
X Exclude Records

Field: Publication Year	Record Count	% of 16	Bar Chart	Save Analysis Data to File
2008	3	18.7500 %		
2002	2	12.5000 %		
2004	2	12.5000 %		
2007	2	12.5000 %		
2009	2	12.5000 %		
2010	2	12.5000 %		
2000	1	6.2500 %		
2001	1	6.2500 %		
2003	1	6.2500 %		

→ View Records
X Exclude Records

Field: Publication Year Record Count % of 16 Bar Chart Save Analysis Data to File

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Analyze Results

16 records. Topic=(flow regime riparian product*)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:
Author
Conference Title
Country/Territory
Document Type

Analyze:
Up to 500 Records.

Set display options:
Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:
Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Source Title	Record Count	% of 16	Bar Chart	Save Analysis Data to File
	ARCHIV FUR HYDROBIOLOGIE	1	6.2500 %		
	BIOGEOCHEMISTRY	1	6.2500 %		
	BOTANICAL REVIEW	1	6.2500 %		
	CHEMIE DER ERDE-GEOCHEMISTRY	1	6.2500 %		
	ECOLOGICAL APPLICATIONS	1	6.2500 %		
	ECOLOGICAL MODELLING	1	6.2500 %		
	FOREST SCIENCE	1	6.2500 %		
	FRESHWATER BIOLOGY	1	6.2500 %		
	HYDROBIOLOGIA	1	6.2500 %		
	JOURNAL OF APPLIED ECOLOGY	1	6.2500 %		
→ View Records ✕ Exclude Records	**Field: Source Title**	**Record Count**	**% of 16**	**Bar Chart**	Save Analysis Data to File

(6 Source Title value(s) outside display options.)

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Analyze Results

16 records. Topic=(flow regime riparian product*)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
× Exclude Records

Field: Subject Area	Record Count	% of 16	Bar Chart	Save Analysis Data to File
ECOLOGY	5	31.2500 %		
ENVIRONMENTAL SCIENCES	5	31.2500 %		
MARINE & FRESHWATER BIOLOGY	3	18.7500 %		
WATER RESOURCES	3	18.7500 %		
GEOSCIENCES, MULTIDISCIPLINARY	2	12.5000 %		
BIODIVERSITY CONSERVATION	1	6.2500 %		
ENGINEERING, CIVIL	1	6.2500 %		
ENGINEERING, ENVIRONMENTAL	1	6.2500 %		
FORESTRY	1	6.2500 %		
GEOCHEMISTRY & GEOPHYSICS	1	6.2500 %		
Field: Subject Area	**Record Count**	**% of 16**	**Bar Chart**	Save Analysis Data to File

→ View Records
× Exclude Records

(2 Subject Area value(s) outside display options.)

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Analyze Results

15 records. Topic=(flow regime wetland product*)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
✕ Exclude Records

Field: Country/Territory	Record Count	% of 15	Bar Chart
USA	10	66.6667 %	
BRAZIL	2	13.3333 %	
AUSTRALIA	1	6.6667 %	
ENGLAND	1	6.6667 %	
NEW ZEALAND	1	6.6667 %	
Field: Country/Territory	**Record Count**	**% of 15**	**Bar Chart**

Save Analysis Data to File

→ View Records
✕ Exclude Records

Save Analysis Data to File

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Analyze Results

15 records. Topic=(flow regime wetland product*)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field: Author, Conference Title, Country/Territory, Document Type

Analyze: Up to 500 Records.

Set display options: Show the top 10 Results. Minimum record count (Threshold): 0

Sort by: Record count / Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count
if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Document Type	Record Count	% of 15	Bar Chart	Save Analysis Data to File
	ARTICLE	14	93.3333 %		
	REVIEW	1	6.6667 %		
→ View Records ✕ Exclude Records	Field: Document Type	Record Count	% of 15	Bar Chart	Save Analysis Data to File

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Analyze Results

15 records. Topic=(flow regime wetland product*)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze:

Up to 500 Records.

Set display options:

Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:

Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records × Exclude Records	**Field: Publication Year**	**Record Count**	**% of 15**	**Bar Chart**	Save Analysis Data to File
	2008	6	40.0000 %		
	2001	2	13.3333 %		
	2000	1	6.6667 %		
	2002	1	6.6667 %		
	2003	1	6.6667 %		
	2004	1	6.6667 %		
	2005	1	6.6667 %		
	2006	1	6.6667 %		
	2007	1	6.6667 %		
→ View Records × Exclude Records	**Field: Publication Year**	**Record Count**	**% of 15**	**Bar Chart**	Save Analysis Data to File

<<< Back to results list

Analyze Results

15 records. Topic=(flow regime wetland product*)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	**Analyze:**	**Set display options:**	**Sort by:**
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

View Records / Exclude Records	**Field: Source Title**	**Record Count**	**% of 15**	**Bar Chart**	Save Analysis Data to File
	AMERICAN MIDLAND NATURALIST	1	6.6667 %		
	ARCHIV FUR HYDROBIOLOGIE	1	6.6667 %		
	AUSTRALIAN JOURNAL OF SOIL RESEARCH	1	6.6667 %		
	BRAZILIAN JOURNAL OF BIOLOGY	1	6.6667 %		
	ECOLOGICAL APPLICATIONS	1	6.6667 %		
	ECOLOGICAL ENGINEERING	1	6.6667 %		
	ECOLOGICAL MODELLING	1	6.6667 %		
	FOREST ECOLOGY AND MANAGEMENT	1	6.6667 %		
	FRESHWATER BIOLOGY	1	6.6667 %		
	JOURNAL OF APPLIED ECOLOGY	1	6.6667 %		
View Records / Exclude Records	**Field: Source Title**	**Record Count**	**% of 15**	**Bar Chart**	Save Analysis Data to File

(5 Source Title value(s) outside display options.)

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Analyze Results

15 records. Topic=(flow regime wetland product*)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:
Author
Conference Title
Country/Territory
Document Type

Analyze:
Up to 500 Records.

Set display options:
Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:
Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
✕ Exclude Records

Field: Subject Area	Record Count	% of 15	Bar Chart	Save Analysis Data to File
ECOLOGY	6	40.0000 %		
ENVIRONMENTAL SCIENCES	5	33.3333 %		
MARINE & FRESHWATER BIOLOGY	3	20.0000 %		
ENGINEERING, ENVIRONMENTAL	2	13.3333 %		
LIMNOLOGY	2	13.3333 %		
WATER RESOURCES	2	13.3333 %		
BIODIVERSITY CONSERVATION	1	6.6667 %		
BIOLOGY	1	6.6667 %		
FORESTRY	1	6.6667 %		
GEOSCIENCES, MULTIDISCIPLINARY	1	6.6667 %		
Field: Subject Area	**Record Count**	**% of 15**	**Bar Chart**	Save Analysis Data to File

→ View Records
✕ Exclude Records

(2 Subject Area value(s) outside display options.)

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Analyze Results

18 records. Topic=(denitrification flow regime)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:
Author
Conference Title
Country/Territory
Document Type

Analyze: Up to 500 Records.

Set display options: Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by: Record count / Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

View Records / Exclude Records — Save Analysis Data to File

Field: Country/Territory	Record Count	% of 18	Bar Chart
USA	7	38.8889 %	
FRANCE	4	22.2222 %	
CANADA	3	16.6667 %	
SPAIN	3	16.6667 %	
ENGLAND	2	11.1111 %	
SCOTLAND	2	11.1111 %	
SWITZERLAND	2	11.1111 %	
AUSTRIA	1	5.5556 %	
BELGIUM	1	5.5556 %	
BRAZIL	1	5.5556 %	

View Records / Exclude Records — Field: Country/Territory — Record Count — % of 18 — Bar Chart — Save Analysis Data to File

(7 Country/Territory value(s) outside display options.)

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Analyze Results

18 records. Topic=(denitrification flow regime)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:

Author
Conference Title
Country/Territory
Document Type

Analyze: Up to 500 Records.

Set display options: Show the top 10 Results.
Minimum record count (Threshold): 0

Sort by:
Record count
Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count
if the original set contained more records than the number of records analyzed.

→ View Records ✕ Exclude Records	Field: Document Type	Record Count	% of 18	Bar Chart	Save Analysis Data to File
	ARTICLE	17	94.4444 %		
	REVIEW	1	5.5556 %		
→ View Records ✕ Exclude Records	**Field: Document Type**	**Record Count**	**% of 18**	**Bar Chart**	Save Analysis Data to File

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Take the next step

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Analyze Results

18 records. Topic=(denitrification flow regime)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records X Exclude Records	Field: Publication Year	Record Count	% of 18	Bar Chart	Save Analysis Data to File
	2007	4	22.2222 %		
	2006	3	16.6667 %		
	2004	2	11.1111 %		
	2005	2	11.1111 %		
	2009	2	11.1111 %		
	2000	1	5.5556 %		
	2001	1	5.5556 %		
	2002	1	5.5556 %		
	2003	1	5.5556 %		
	2008	1	5.5556 %		
→ View Records X Exclude Records	**Field: Publication Year**	**Record Count**	**% of 18**	**Bar Chart**	Save Analysis Data to File

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Analyze Results

18 records. Topic=(denitrification flow regime)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records X Exclude Records	Field: Source Title	Record Count	% of 18	Bar Chart	Save Analysis Data to File
	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	1	5.5556 %		
	AQUATIC CONSERVATION-MARINE AND FRESHWATER ECOSYSTEMS	1	5.5556 %		
	AQUATIC MICROBIAL ECOLOGY	1	5.5556 %		
	BIOGEOCHEMISTRY	1	5.5556 %		
	ECOLOGICAL ENGINEERING	1	5.5556 %		
	ENVIRONMENTAL GEOLOGY	1	5.5556 %		
	ENVIRONMENTAL MANAGEMENT	1	5.5556 %		
	ENVIRONMENTAL TECHNOLOGY	1	5.5556 %		
	GEOCHIMICA ET COSMOCHIMICA ACTA	1	5.5556 %		
	HYDROLOGICAL PROCESSES	1	5.5556 %		
→ View Records X Exclude Records	Field: Source Title	Record Count	% of 18	Bar Chart	Save Analysis Data to File

(8 Source Title value(s) outside display options.)

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Analyze Results

18 records. Topic=(denitrification flow regime)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records X Exclude Records	Field: Subject Area	Record Count	% of 18	Bar Chart	Save Analysis Data to File
	ENVIRONMENTAL SCIENCES	12	66.6667 %		
	WATER RESOURCES	8	44.4444 %		
	GEOSCIENCES, MULTIDISCIPLINARY	4	22.2222 %		
	ECOLOGY	3	16.6667 %		
	ENGINEERING, ENVIRONMENTAL	3	16.6667 %		
	LIMNOLOGY	3	16.6667 %		
	MARINE & FRESHWATER BIOLOGY	3	16.6667 %		
	AGRICULTURE, MULTIDISCIPLINARY	1	5.5556 %		
	ENGINEERING, CIVIL	1	5.5556 %		
	ENGINEERING, GEOLOGICAL	1	5.5556 %		
→ View Records X Exclude Records	Field: Subject Area	Record Count	% of 18	Bar Chart	Save Analysis Data to File

(6 Subject Area value(s) outside display options.)

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Analyze Results

108 records. Topic=(wetlands) AND Topic=(carbon) AND Topic=(cycling)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records ✗ Exclude Records	Field: Country/Territory	Record Count	% of 108	Bar Chart	Save Analysis Data to File
	USA	72	66.6667 %		
	CANADA	14	12.9630 %		
	GERMANY	13	12.0370 %		
	NETHERLANDS	6	5.5556 %		
	SWEDEN	5	4.6296 %		
	PEOPLES R CHINA	4	3.7037 %		
	AUSTRALIA	3	2.7778 %		
	CZECH REPUBLIC	3	2.7778 %		
	FINLAND	3	2.7778 %		
	ITALY	3	2.7778 %		
→ View Records ✗ Exclude Records	Field: Country/Territory	Record Count	% of 108	Bar Chart	Save Analysis Data to File

(14 Country/Territory value(s) outside display options.)

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Analyze Results

108 records. Topic=(wetlands) AND Topic=(carbon) AND Topic=(cycling)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records × Exclude Records	Field: Publication Year	Record Count	% of 108	Bar Chart	Save Analysis Data to File
	2008	19	17.5926 %		
	2007	16	14.8148 %		
	2004	11	10.1852 %		
	2005	11	10.1852 %		
	2009	10	9.2593 %		
	2000	8	7.4074 %		
	2001	7	6.4815 %		
	2002	7	6.4815 %		
	2006	7	6.4815 %		
	2010	7	6.4815 %		
→ View Records × Exclude Records	**Field: Publication Year**	**Record Count**	**% of 108**	**Bar Chart**	Save Analysis Data to File

(2 Publication Year value(s) outside display options.)

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Analyze Results

108 records. Topic=(wetlands) AND Topic=(carbon) AND Topic=(cycling)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records × Exclude Records	Field: Source Title	Record Count	% of 108	Bar Chart	Save Analysis Data to File
	BIOGEOCHEMISTRY	9	8.3333 %		
	WETLANDS	8	7.4074 %		
	ECOSYSTEMS	5	4.6296 %		
	ECOLOGICAL ENGINEERING	4	3.7037 %		
	GEOMICROBIOLOGY JOURNAL	4	3.7037 %		
	GLOBAL BIOGEOCHEMICAL CYCLES	4	3.7037 %		
	SOIL BIOLOGY & BIOCHEMISTRY	4	3.7037 %		
	BIOGEOSCIENCES	3	2.7778 %		
	ECOLOGICAL MODELLING	3	2.7778 %		
	FOREST ECOLOGY AND MANAGEMENT	3	2.7778 %		
→ View Records × Exclude Records	**Field: Source Title**	**Record Count**	**% of 108**	**Bar Chart**	Save Analysis Data to File

(52 Source Title value(s) outside display options.)

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Analyze Results

108 records. Topic=(wetlands) AND Topic=(carbon) AND Topic=(cycling)
Analysis: Document Type=(ARTICLE OR REVIEW)

Rank the records by this field:	Analyze:	Set display options:	Sort by:
Author Conference Title Country/Territory Document Type	Up to 500 Records.	Show the top 10 Results. Minimum record count (Threshold): 0	Record count Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others)..
Note: The number of records displayed may be greater than the listed Record Count if the original set contained more records than the number of records analyzed.

→ View Records
× Exclude Records

Field: Subject Area	Record Count	% of 108	Bar Chart	Save Analysis Data to File
ENVIRONMENTAL SCIENCES	49	45.3704 %		
ECOLOGY	32	29.6296 %		
GEOSCIENCES, MULTIDISCIPLINARY	25	23.1481 %		
SOIL SCIENCE	16	14.8148 %		
ENGINEERING, ENVIRONMENTAL	9	8.3333 %		
WATER RESOURCES	9	8.3333 %		
MARINE & FRESHWATER BIOLOGY	7	6.4815 %		
PLANT SCIENCES	7	6.4815 %		
METEOROLOGY & ATMOSPHERIC SCIENCES	6	5.5556 %		
LIMNOLOGY	5	4.6296 %		
Field: Subject Area	**Record Count**	**% of 108**	**Bar Chart**	Save Analysis Data to File

→ View Records
× Exclude Records

(15 Subject Area value(s) outside display options.)

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