Socio-hydrologic change in the upper Arkavathy catchment, India

*Veena Srinivasan[1], Apoorva R.[1], Gopal Penny[2], Sharachchandra Lele[1], Sally Thompson[2]

1. Ashoka Trust for Research in Ecology and the Environment, 2. University of California, Berkeley

The developing world faces unique challenges in achieving water security as it is disproportionately exposed to stressors such as climate change while also undergoing demographic growth, agricultural intensification and industrialization. Investigative approaches are needed that can inform sound policy development and planning to address the water security challenge in the context of rapid change and data scarcity.
We investigated the ``predictions under change" problem in the Thippagondanahalli (TG Halli) catchment of the Arkavathy sub-basin in South India. River inflows into the TG Halli reservoir have declined since the 1970s, and the reservoir is currently operating at only 20% of its built capacity. The mechanisms responsible for the drying of the river are not understood, resulting in uncoordinated and potentially counter-productive management responses. The objective of this study was to investigate potential explanations of the drying trend and thus obtain predictive insight.
Our approach was then to develop a set of hypotheses of what broad factors might be contributing to drying using available data -- was it declining rainfall, rising temperatures, groundwater pumping, eucalyptus plantations or stream fragmentation? The historical data clearly showed that changes in rainfall and temperature could not explain the sharp declines in streamflow.
Having broadly established that groundwater pumping, stream fragmentation and eucalyptus were responsible for the river drying, the next task was to understand the processes at work and their interaction. To do this we embarked on an intensive three year field study to test various hypotheses including household and farm surveys, focus group discussions, isotopic studies, analysing satellite imagery, borewell camera scans, streamflow and soil moisture sensors, weather stations and a participatory groundwater monitoring programme.
The farmer survey showed clearly that as Bangalore city grew, farmers follow a "go big or quit" strategy. It makes no sense for farmers in nearby rural areas to continue in rainfed agriculture - they were better off either putting their land under eucalyptus and going to work in the city. Farmers who remain in agriculture can only justify it by drilling deep borewells to grow irrigated high-value crops that could be sold in the city or exported. The hydrologic studies showed that the pumping was causing groundwater to decline sharply. The eucalyptus trees were taking up much of the infiltrated water and decreasing recharge. The policy response to declining groundwater was to set up check dams to boost recharge but all this did was to accelerate stream flow decline. Because electricity is free and borewell drilling is relatively affordable, there is no limit on how much water humans are abstracting from the system. The net impact is an increase in ET in the upper catchment over time and a decrease in downstream flows to the reservoir

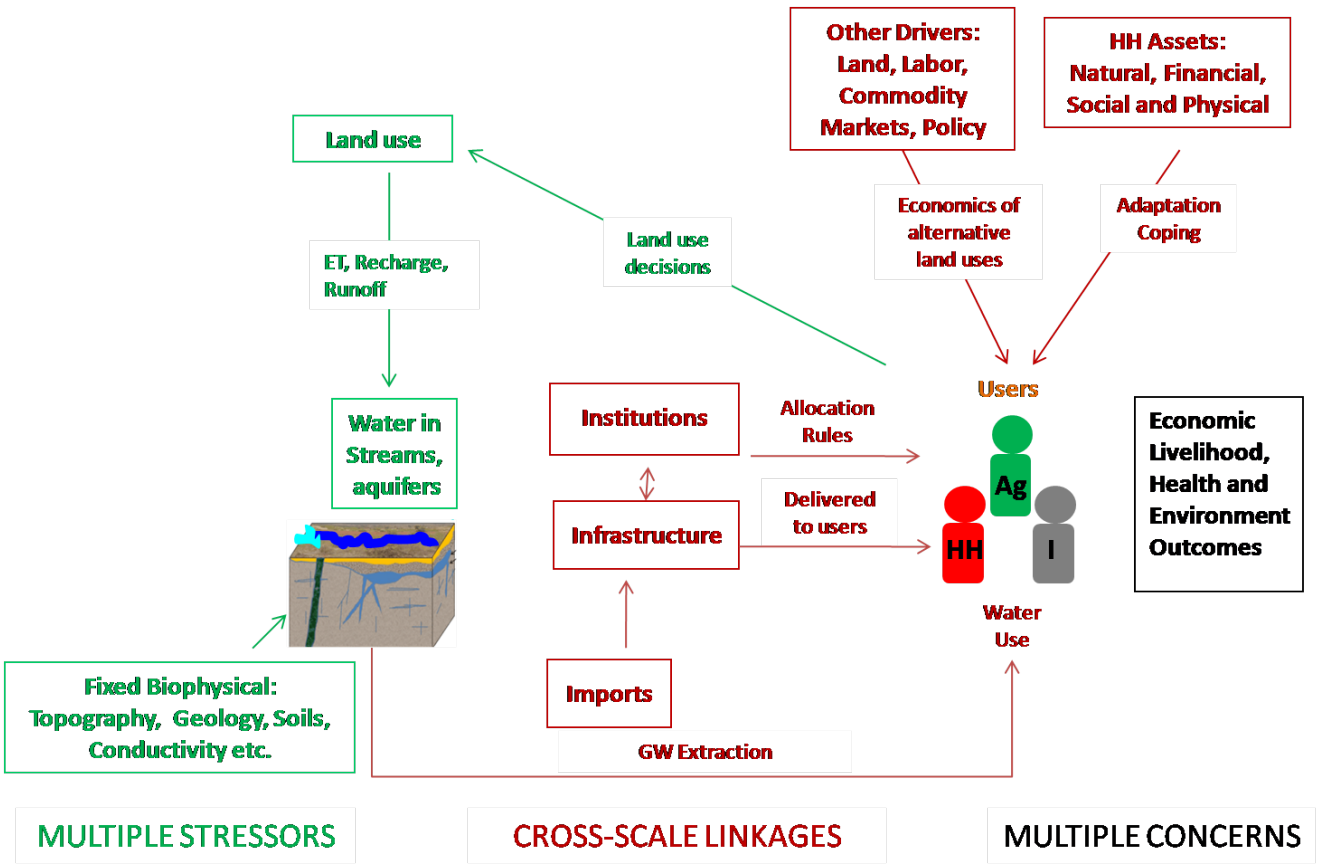
The research led us to conclude, that first humans are both changing the system and in turn responding to environmental change. The impact of urbanisation (an exogeneous driver) was not merely hydrologic in terms of infiltration or ET but a change in land, labour and commodity markets that in turn had severe consequences on the hydrology.

Second, the hard rock geology meant that groundwater storage is limited. In effect the aquifer only acts as a buffer storage (it stores rainfall in wet periods so it can be used in dry periods); overall rainfall remains the limiting factor. t

Third, not only is total use unsustainable it is also inequitable; the water is locally captured by just a handful of large irrigators. But the combination of borewells, eucalyptus and check dams results in an "upstream shift" of the water which has its own basin-level equity implications.

In the long term, the only option (in the absence of inter-basin imports) is to stay within the water resources available through enforceable limits on water abstraction via a water budgeting exercise at both the local and regional scale.

Keywords: socio-hydrology, urbanisation, groundwater, India, check dam, climate



Net anthropogenic nitrogen inputs and their impacts on stream water quality in the upper Yangtze River

*Dawen Yang[1]

1. Tsinghua University

Various human activities influence not only the hydrological cycle but also the nitrogen cycle in a river basin. Nitrogen inputs to the river basin are increasing due to the increasing human activities, and the nitrogen input increasing have caused many water environmental problems. Understanding the interactions between human activities and hydrological processes is important for predicting the changes of water quantity and quality. This research selected the upper Yangtze River basin as the study area, and analyzed spatio-temporal variation of the net anthropogenic nitrogen inputs (NANI). To predict nitrogen inputs into the river and their impacts on river water quality, a distributed hydrological model coupled with the non-point source pollution was developed considering the interactions between human activities and hydrological processes. Based on the simulation results, it analyzed the characteristics of hillslope nitrogen loading and the impact on river water quality. The results obtained in the upper Yangtze River basin demonstrated that the major nitrogen sources were the agricultural fertilizer application, atmospheric nitrogen deposition and food/feed nitrogen input. The high values of NANI were concentrated in Chengdu Plain. Increasing urban area has changed the ways of farming and cultivation in cities and surrounding cities, which resulted in the increasing NANI. The simulated results also showed that annual total nitrogen loading was 1.50 ton/km^2 in the upper Yangtze River basin. The amount of nitrogen loading in July and August took more than 65% of the annual total nitrogen and the export coefficient of nitrogen was 0.26 at Yichang station, which was influenced by both artificial nitrogen inputs and the natural hydrological processes. The nitrogen concentrations in the stream waters are high in the rainy season because of strong interaction of hydrological processes with the human activities.

Keywords: net anthropogenic nitrogen inputs, hydrological processes, human activities, stream water quality, interaction between hydrological processes and human activities

Impact of climate change and human development on future freshwater availability in Africa

*Luigi Piemontese[1,3], Fernando Jaramillo[1,2], Ingo Fetzer[1], Johan Rockström[1]

1. Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden., 2. Department of Physical Geography, Stockholm University, Stockholm, Sweden., 3. Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden

With a constantly growing global population, ensuring a sustainable food production is one of the biggest challenges that humanity is expected to face in the near future. Moreover climate change is adding pressure on our planet; indeed according to the Intergovernmental Panel on Climate Change (IPCC), CO2 emissions will be responsible for changes in temperature and precipitation distribution with unforeseen consequences on freshwater availability for agriculture. Based on the modelling work of the Coupled Model Intercomparison Project (CMIP5), we conduct a systematic analysis of long-term climate forecasts in order to identify and quantify signals of human development on freshwater consumption in the main African river basins. An ensemble of climatic and land variables from CMIP5's outputs - mainly temperature, precipitation, runoff and land cover - for the period 2006-2100 was used to calculate actual evapotranspiration and the evaporative ratio (ratio of actual evapotranspiration to precipitation) through water balance. These parameters were evaluated within the Budyko framework - a hydroclimatic analysis tool that links water availability and energy demand - as obtained from a selection of climate simulations with different emission scenarios to determine potential hydroclimatic change. Some of the those simulations include land cover forecasts, allowing to map out the land use change pathways and discern the relative impact of land and climatic drivers on forthcoming freshwater availability.
By analyzing rose plots for change in Budyko space we found that freshwater availability is changing in a heterogeneous way across the continent in terms of both intensity and directions. Some common patterns emerges across all the models within African basins. In particular, the most serious CMIP5 emission scenario, shows consistent increasing trends of the ratio of potential evapotranspiration to precipitation while less congruous results appear for the evaporative ratio in the model simulations. The first can be explained by the strong dependence of potential evapotranspiration on temperature, which experience an increasing trend due to global CO2 emissions. On the other hand, the evaporative ratio is linked to many complex ocean-land-atmosphere dynamics, which are very sensitive to model components and settings. Directions and magnitudes of such a change in hydroclimatic signals vary from model to model and can be interpreted as evidence of climate change and land use change effects, according to models design characteristics. Considerations about combined climate and land change effect on evapotranspiration is thus deduced by discerning from model land cover components, and the effect on future freshwater use trends is calculated with this methodology.
The applied methodology and results of this study can be a useful tool to bridge the state of the art in climate modelling to climate change mitigation strategies, supporting policy makers to develop sustainable water management and land use change practices.

Keywords: Future freshwater consumption, Budyko framework, Africa

Size and stochasticity in irrigated socio-hydrological systems

*Rachata Muneepeerakul[1], Arnald Puy[2,3], Andrea L. Balbo[4]

1. University of Florida, USA, 2. University of Haifa, Israel, 3. Universität zu Köln, Germany, 4. University of Hamburg, Germany

Here we present a systematic study of the relation between the size of socio-hydrological systems and stochastic forcing. In particular, through a stylized theoretical model, we focus on how stochasticity in water availability and taxation interacts with the stochastic behavior of the population within irrigated socio-hydrological systems. Our results indicate the existence of two key population levels for the sustainability of such systems: (i) the critical population size required to keep the system operative--with a smaller population size, the system may self-organize toward a collapse; and (ii) the population threshold at which the incentive to work inside the system equals the incentive to work elsewhere—the system will self-organize toward this level, despite sub-optimal per capita payoff to its population. When subjected to strong stochasticity in water availability or taxation, the system may suffer sharp population drops and irreversibly disintegrate into a system collapse, via a mechanism we dub ‘collapse trap.’ Our theoretical study establishes the basis for further work aiming at understanding the dynamics between size and stochasticity in irrigated systems, which is key for devising mitigation and adaptation measures to ensure their sustainability in the face of increasing and inevitable uncertainty.

Keywords: Coupled natural-human systems, Stochasticity, Agriculture, Regime shift

Hydro-social Metabolism: Scaling of population growth and water use of nations

*Saket Pande[1]

1. Delft University of Technology

Water is important for human life. It is the carrier of nutrients, amongst other things, that control human metabolism. Metabolism, which is a process of transforming energy and materials for work or biomass generation, is one key process that has been hypothesised to control population growth of multiple species as well as flux exchange between species or constituents of an ecosystem. A -1/3 power scaling between population growth rates and rates linked to metabolism such as biomass production or rate of energy consumption has been observed spanning >20 orders of magnitude in body size (from zooplanktons to mammals).

Central hypothesis of this paper is that water flux controls the average human metabolism of nations and hence population growth rates. United Nations population statistics and water use of regions (Africa, Asia, North America, Europe, Australia and Latin America) from 1950 to 2000 at irregular 5 years intervals are used to reveal the power scaling between the two. In addition, strikingly similar inter-temporal dynamics in between industrialized regions (North America, Europe, Australia) and in between less developed regions (Africa, Asia) is found. The dynamics across these two clusters of regions is similar in only one respect. The per capita water use and birth rates in both the clusters of regions follows a trajectory that first sees increasing per capita water use with decreasing birth rates followed by decreasing (or constant in case of Africa and Asia) per capita water use with decreasing birth rates. These trajectories demonstrate path dependency of the co-evolution of water use with population growth on the past and corroborate with increased labor participation of women in the industrialized world and perhaps with post-colonial transition in Africa and Asia.

Nonetheless, at any given point in time, all regions appear to always lie on the -1/3 power law relationship between human water use and population growth rates. This offers support to the second hypothesis of this paper, that the -1/3 power law relationship between nations at any point in time is independent of the temporal co-evolution of water use with population growth.

If the above hypotheses are found to hold valid with finer national scale data at more regular time intervals, this may indicate that humans are no different than non-human primates, other mammals and organisms in being governed by the relationship and that nation states are organisms whose water use and birth rates are constrained by hydro-social metabolism.

Keywords: coupled human-water systems, socio-hydrology, social metabolism, population growth, water use

Commodity flows across spatial scales

*Megan Konar[1], Xiaowen Lin[1], Benjamin Ruddell[2]

1. University of Illinois at Urbana Champaign, 2. Northern Arizona University

Commodity flows are the spatial and temporal redistribution of goods. Recently, there has been a surge of research in international trade in the scientific literature, primarily due to an interest in the natural resources embodied in the traded commodities (e.g. water, carbon, nutrients). International trade is typically measured annually between countries, but commodity flows occur at many different scales, though data availability at finer temporal and spatial resolutions is typically limiting. Here, we present an empirical analysis of commodity flows in primary units (i.e. mass and value) across three spatial scales: global, national, and village. To do this, we obtain data on international trade, national commodity flows of the United States, and village commodity flows in Alaska. Importantly, we segment the data into food and non-food commodity classes to evaluate the unique features of food flows. We determine the network properties of commodity flows for each spatial scale, finding that node degree distributions are fit by normal distributions, node strength distributions are fit by Weibull distributions, and a power law relationship exists between node degree and strength across scales. A core group of nodes exists in each network. This work sheds light on the scaling properties of commodity flows, indicating some unifying underlying mechanisms and can be used to estimate commodity flows at scales for which empirical information is not available.

Keywords: Commodity flows, Scale, Networks

Asymmetry of agricultural water consumption in arid regions during alternating decadal scale wet and dry periods: explanation using behavioral economics

*Fuqiang Tian[1]

1. Tsinghua University

Increase of human water consumption for agriculture and consequent degradation of the ecological environment is a common feature in many arid regions. Understanding the driving mechanisms behind this phenomenon is of critical importance for regional sustainable development. In this study, analyses of temporal patterns of human water consumption are carried out in three hyper-arid inland basins, i.e., Aral Sea Basin in Central Asia, and the Tarim and Heihe River Basins in Northwestern China. Multi-decadal time series of hydrological and human consumption data are divided into decadal sequences of wet and dry years. During the wet phases, the greater water availability inspires economic expansion and human water consumption experiences growth at a rate faster than that of incoming water. During the dry phases, however, the expanded economy (e.g., irrigation land expansion in an agriculture-based economy) has been managed to sustain or even to increase production by over-exploitation of water with sophisticated technologies. Inability to reduce human water consumption at a rate commensurate with the decrease of incoming water supply leads to serious ecosystem degradation. This asymmetric human water consumption response of society to decadal scale hydrologic variability can be explained in terms of prospect theory drawn from behavioral economics, which states that people tend to be risk averse when facing gains and show risk preference when facing losses. In the three socio-hydrological case studies, direct economic gain/loss has relatively low value but high certainty when compared to indirect economic loss/gain (such as environmental or sustainability loss/gain), which has high value but with high uncertainty. According to prospect theory, people tend to gain direct economic benefits at the expense of environmental degradation and at the risk of system collapse. The outcomes of this study have major implications for water resources management at long time scales, and in particular calls for increased understanding of human-water system interactions and feedbacks at the decadal time scale.

Keywords: sociohydrology, decadal variability, human water consumption

A behavioral approach to understanding human-water interactions under hydrological variability

*David J. Yu[1], Hoon C. Shin[2], Irene Perez[2], John M. Anderies[2], Marco A. Janssen[2]

1. Purdue University, 2. Arizona State University

One approach recently proposed for studying the interactions between hydrology and the social components is the use of an interactive interface that allows observations of human decision-making in response to simulated hydrologic events. However, despite its potential to generate empirical data on human-water interactions, such an interactive method involving actual people has been rarely used in the study of socio-hydrology. We suggest that laboratory behavioral experiments, or experimental economics, can be a useful research method that can help bridge this gap. For example, in the field of socio-ecological systems research, behavioral experiments are increasingly being used to study human behavioral response to ecological dynamics. This study showcases a behavioral experiment designed to study human-water interactions in the context of irrigated agriculture. In this experiment, human-subjects are faced with a set of decision problems on collective management of shared irrigation infrastructure in the face of hydrological variability. We generate new hypotheses regarding how humans should learn to anticipate and build adaptive capacity to extreme hydrological variability by comparing the decisions of human-subject groups that participated in the experiment. Our findings suggest that under hydrological stability, groups may be able to perform well without frequent adjustments to their strategy. They can still succeed as long as they tightly coordinate on shared strategies along with active monitoring of their irrigation system and user participation in decision-making. However, such groups may be fragile under hydrological variability. Only the groups that experience active learning, monitoring of irrigation system, and probing of the boundaries of their status-quo strategies are likely to remain resilient under hydrological variability.

Keywords: behavioral experiment, irrigation system, socio-hydrology

Water in a Warming World: Exploring the nexus of Climate Change, Water, and Human Values

*Daniel Close Larson[1]

1. Portland State University

The Portland, Oregon Metro region is faced with rapid urbanization and as the demand for hydrologic ecosystem services increases, so does encroachment into undeveloped upland reaches of the watershed along with the negative environmental and social externalities that ensue. To mitigate this damage, water managers must design source water protection programs that incorporate the negative effects of water quality degradation due increased urbanization and potential adverse effects of climate change. In order to do this water managers must understand water utility ratepayers attitudes and preferences towards source water protection programs and climate change. We investigated customer support, more specifically Willingness-to-Pay (WTP) for source watershed protection programs, environmental values, climate change beliefs, and other policy instruments. The sample was comprised of 466 greater Portland, Oregon area residents. Respondents overwhelmingly indicated support for restriction programs and education programs, with a lack of support for financial assistance programs. Respondents largely distrusted non-profit organizations and federal agencies for implementing effective source watershed protection. Multi-variate analysis revealed that greater trust in local conservation agencies, recognition in the consequences of climate change, sense of place, higher income, and education were strong predictors of greater policy support. Personal values and political affiliation were good indirect predictors of policy support.

Keywords: WTP, CHANS, Climate Change, Watershed Protection

Drought in the Anthropocene: examples from around the world

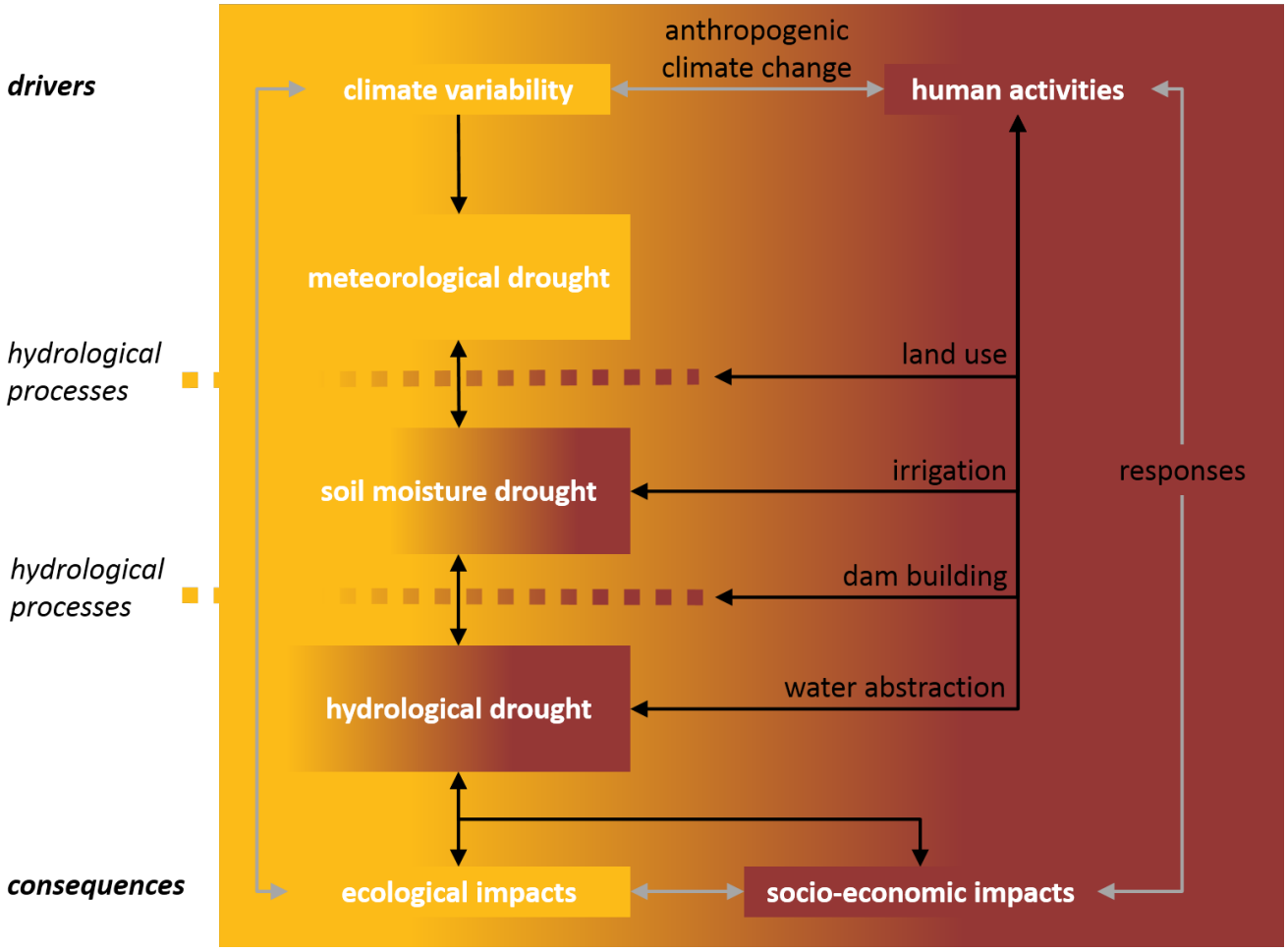
*Anne Frederike Van Loon[1], Sally Rangecroft[1], Henny A.J. Van Lanen[2]

1. School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, United Kingdom, 2. Hydrology and Quantitative Water Management Group, Wageningen University, Wageningen, the Netherlands

In the current human-modified world, or 'Anthropocene', the state of water stores (soil water, groundwater) and fluxes (river flow) has become dependent on human actions as well as on natural processes. Hydrological droughts are the result of a complex interaction between meteorological anomalies, land surface processes, and human inflows, outflows and storage changes. Our current inability to adequately analyse and manage drought in many places points to gaps in our understanding of this interaction and to inadequate data and tools to study it in depth. The Anthropocene requires a new framework for drought concepts, definitions and research. To progress the field, the drought conceptual framework needs to be revisited to explicitly include human processes driving and modifying hydrological drought development. Here we will give recommendations for more robust drought definitions in the Anthropocene, distinguishing between climate-induced, human-induced and human-modified hydrological drought. Additionally, our understanding and analysis of drought need to move from single driver (i.e. meteorological anomalies) to multiple drivers (i.e. meteorological anomalies and anthropogenic water abstraction) and from uni-directional (i.e. propagation from driver to drought to impacts on society) to multi-directional (i.e. feedback responses from society that affect drought). Based on literature reviews, our own previous work and current studies done through the Panta Rhei network, we visit example catchments around the world where human and natural drought processes are strongly interrelated. We discuss drought development in relation to natural and human drivers, responses to drought, both positive (i.e. more abstraction aggravating drought) and negative (i.e. water management alleviating drought) feedbacks, with the aim to get a more general understanding about drought in the Anthropocene. Based on the case studies, we identify research gaps and propose analysis approaches for drought in the Anthropocene, requiring qualitative and quantitative data as well as mixed modelling approaches on different scales. We expect this will shape the drought research agenda for the coming years, or even decade.

This work has been developed in the framework of the IAHS Panta Rhei working group "Drought in the Anthropocene".

Keywords: drought, Anthropocene, conceptual framework



Optimal investment and location decisions of a firm in a flood risk area using Impulse Control Theory

*Johanna Grames[1], Dieter Grass[1], Peter Kort[2,3], Alexia Prskawetz[1,4]

1. Vienna University of Technology, 2. Tilburg University, 3. University of Antwerp, 4. Wittgenstein Centre (IIASA, VID/ÖAW, WU), Vienna Institute of Demography

Flooding events can affect businesses close to rivers, lakes or coasts. This paper provides a partial equilibrium model which helps to understand the optimal location choice for a firm in flood risk areas and its investment strategies. How often, when and how much are firms willing to invest in flood risk protection measures? We apply Impulse Control Theory and develop a continuation algorithm to solve the model numerically.
We find that, the higher the flood risk and the more the firm values the future, i.e. the more sustainable the firm plans, the more the firm will invest in flood defense. Investments in productive capital follow a similar path. Hence, planning in a sustainable way leads to economic growth. Sociohydrological feedbacks are crucial for the location choice of the firm, whereas different economic settings have an impact on investment strategies. If flood defense is already present, e.g. built up by the government, firms move closer to the water and invest less in flood defense, which allows firms to accrue higher expected profits. Firms with a large initial productive capital surprisingly try not to keep their market advantage, but rather reduce flood risk by reducing exposed productive capital.

Keywords: optimal investment, location choice, flood, socio-hydrology, Impulse Control Theory, sustainability

Climate change risk assessment by Integrated Terrestrial Model: a bio-geophysical land surface model with human components

*Tokuta Yokohata[1], Akihiko Ito[1], Naota Hanasaki[1], Gen Sakurai[2], Tsuguki Kinoshita[3], Toshichika Iizumi[2], Yoshimitsu Masaki[4], Tomoko Nitta[5], Yadu Pokhrel[6], Yusuke SATOH[7], Seita Emori[1]

1. National Institute for Environmental Studies, 2. National Agriculture and Food Research Organization, 3. Ibaraki University, 4. Hirosaki University, 5. University of Tokyo, 6. Michigan State University, 7. International Institute for Applied System Analysis

Future climate changes possibly affect eco-system services, water resources, food production, energy supply, etc. It is important to understand the interaction between the changes in these complicated factors. In the present study, we develop an integrated terrestrial model which describes the natural biogeophysical environment as well as human activities. In the integrated model, a global vegetation model VISIT (Ito et al. 2012), water resource model H08 (Hanasaki et al. 2008, Pokhrel et al. 2012), crop growth model PRYSBI2 (Sakurai et al. 2015), and land use model TeLMO (Kinoshita et al., in preparation) are coupled to a land surface model MATSIRO (Takata et al. 2003, Nitta et al. 2014), which is a component of global climate model MIROC (Watanabe et al. 2010). Output variables of each sub-model are passed to other sub-models during the time integration. The time intervals of variable exchange are from hourly to monthly or yearly. For example, the crop yields [ton/ha] calculated by PRYSBI2 is used in TEMO which calculate the land use change (crop or natural vegetation area) of next year. The projected land-use map is used in all other sub-models. The water resource model H08 considers the irrigation process (water withdrawal from rivers) as well as dam operations in large rivers, which affects the state of the soil moisture and the river flows in the land surface model. We will present the state of the model development, and results from the historical and future simulation. In the historical simulation, we validated the model output such as river flow, irrigated water, crop yield, and ecosystem productions by comparing to the observed or reanalysis data. Based on the future simulation, we also assessed the risk of future climate change by investigating the relationship of possible cropland area expansion and crop productions and so on.

Keywords: Climate change, Water resources, Land use

