UNESCO Working Group on the impacts of climate variability and land-cover change on flooding and low flows as a function of scale

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Abstract In the context of the IHP-VI Project 2.1 (Extreme events), and the cross-cutting activities of the FRIEND and HELP programmes, the UNESCO Division of Water Sciences has initiated a working group on identifying the relative role of climatic variability and land-cover change on floods and low flows as a function of spatial scale. The mandate of the working group is to summarize the state of the art of the subject, develop the key science questions, plan a five year research strategy for testing in HELP basins and other research experimental basins, and plan a series of workshops. This paper summarizes the findings of the first working group meeting held in Vienna during November, 2005.

Key words floods; low flows; land use; climate change; scale; scaling

INTRODUCTION

Land use, land cover and climate are linked in complex ways. While land-use change often drives environmental changes, a changing climate can in turn affect land use. Because of these links, changes of both systems are important contributors to the magnitude of change and variability of different hydrological processes, in particular to floods and droughts. In addition, such interlinked changes are likely to affect ecosystems and society.

Determining the effects of land-use change on floods and droughts depends on an understanding of land-use practices, current land-use management as affected by society, economic development, technology, and other factors. HELP basins with diverse land-use practices under a variety of climatic conditions in different parts of the world, highlight differences in regional and national vulnerability and resilience, constitute a variety of natural and socio-economic environments and form a focus for the study of scientific questions connected to these changes.

To address such overarching questions, there is a need for a focused, integrated research agenda. This should include observations, experimental research, process studies, modeling and prediction at different scales. The challenge of collaboration is vital, HELP basins can play a catalytic role among scientists and other research programmes to gain understanding of the direct impacts of land-use change on climate, as well as the combined effects of land use and climate change on floods and droughts.

The HELP (Hydrology for the Environment, Life and Policy) programme has been created to cut across all themes of the International Hydrological Programme (IHP) of UNESCO. Specifically, the aim of the HELP programme is to deliver social, economic and environmental benefit to stakeholders through sustainable and appropriate use of water by directing hydrological science towards improved integrated catchment management basins (http://www.unesco.org/water/ihp/help). In the context of the IHP-VI Project 2.1 (Extreme events), and the cross-cutting activities of the FRIEND and HELP programmes, the UNESCO Division of Water Sciences has initiated this working group on identifying the relative role of climatic variability and land cover change on floods and low flows as a function of spatial scale. The mandate of the working group, over a period of five years, is to

- summarize the state of the art of the subject, in particular, to identify at what scales each of the controls become important;
- develop the key science questions;
- plan a five year research strategy for testing in HELP basins and other experimental research basins;
- plan a series of workshops and potential publications from the workshops;
- consider possible locations of the workshops, one per year; and
- any other follow-up activities that the group may identify.

The research strategy should integrate modelling requirements with field experimental hydrology. These activities will provide a road map of how to address these issues and act as a catalyst for motivating communication and targeted research. This paper summarizes the findings of the working group meeting held in Vienna, 28–30 November 2005.

Hydrology is a context dependent discipline, i.e. it matters *where*/*when*/*how* processes occur. For example, land cover effects in the tropics are fundamentally different from those in humid climates. In different hydrological settings the impacts will become important at different scales. With these specifications, the science question to be addressed by the present working group was thus identified as: What are the relative roles of climatic variability and land-cover change on floods and low flows as a function of scale in different environments?

PROCESSES

Land cover is typically a local phenomenon, so its impact is likely to strongly decrease with catchment size. The position of the disturbance in the landscape will modulate the scale effects. In contrast, climate impacts may occur at larger scales so one would expect them to be apparent in both small and large catchments and be consistent in a region. River training impacts are likely to increase with catchment size as there is a general tendency for larger settlements and hence large-scale flood protection works on larger streams. The schematic of Fig. 1 visualizes hypothesized relative roles of climate and land-use changes. Note that the relative roles of these (crossover point on the figure) is likely to vary from catchment to catchment. These are general considerations and the impacts and their scales may differ widely between different hydrological settings. For the particular case of catchments in the Sahel, analyses by Mahé *et al.* (2005a) suggest that environmental change effects in runoff stem, in equal parts, from climate oscillation and land-cover changes. However, very little is known about the scales of impact of the various controls that can be generalised to different environments.

From a methodological perspective, the concept of change is central to the mission of the working group. Questions such as: "how do the various Earth science disciplines consider change, what are suitable methods of change analysis/detection, what feedbacks of land cover/climate impacts on water resources exist", will stand at the forefront of the research agenda and stimulate exchange between various disciplines.

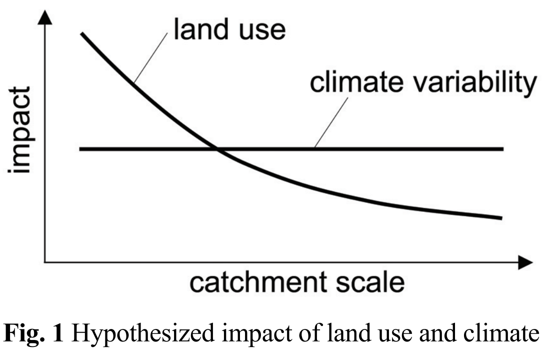

Fig. 1 Hypothesized impact of land use and climate variability on hydrological response as a function of scale.

The type of change may be closely related to the degree of nonlinearity of the system as well as any feedback effects present in the system. Climate regimes may change over a spectrum of time scales and may involve changes in the El Niño/ENSO cycles. Land cover and climate variability effects on floods and low flows are strongly controlled by the flow paths in catchment systems that differ in their time scales and the degree of connectivity. As to flow paths, there are two key issues. The first is: How do land use change and climate variability modify flow pathways and storage? The second, related, issue is: What are the changes in soil structure due to vegetation changes? Different mosaics of land-cover types exist and will impact in a complex way on low flows and floods. In assessing the effects of changes in the inputs to the system output and/or the system characteristics, the way the components interact are important, i.e. feedbacks may either exaggerate a disturbance or stabilize the system.

However, as data never exhaustively represent the hydrological environment, heterogeneity and scale effects enter the scene in impact analyses. A key issue is how to combine measurements and models across a range of scales (Blöschl, 2006). In the context of the implications of the current science question, an important issue is how changes in the hydraulic characteristics of soil, due to vegetation changes, transfer to larger scales and what is the interplay of groundwater dynamics and stream flow dynamics in response to changed land cover and climate variations. This is related to the feedback issues mentioned above. Of general interest is: how one can upscale local information on soils, vegetation, groundwater and surface water–groundwater interactions to the scale of HELP basins (10 000 km^2)?

Methodological perspectives of change and feedbacks, drawing from different Earth science disciplines are also of interest in this respect. Issues to be addressed include: how do floods and low flows change with time and what are the feedback mechanisms controlling them, what are the positive and negative feedback loops, how does the water balance affect runoff components (interactions between long and short time scales), what are the changes in the coupling between groundwater and surface water linked with land cover change.

MANAGEMENT ISSUES

The HELP programme has a management focus. Issues of climate and land cover impact on hydrological response are management relevant in a range of climates, particularly, if financial and sustainability impacts are involved such as in the salinity problems in parts of Australia. Often, incentives are necessary for land managers and end-users to cooperate. For example, the land care programme on salinity in Australia was successful as farmers were loosing money or land unless they cooperated. With nitrate issues in the UK, for example, a lower level of cooperation was observed as there is less obvious economic incentive. Other economic incentives for land managers may be to keep jobs in the region. In many countries, there is a tendency for water management to be short-term profit driven or driven by emergency requirements, e.g. drought in poorer countries. From a land development perspective, a key issue is how far one can develop a catchment before significantly impacting on the sustainability of water resources. Assessment tools include measurements and scenario analyses of the impact of alternative management strategies (Kepner *et al*., 2004). Scenarios can include quantified recharge and surface water–groundwater exchanges.

The management focus of HELP provides a special challenging framework for science questions concerning climate variability and land cover changes, flow path changes in response to such forcing, and the effects of these on low flows and floods. Issues to be addressed could consider how one can best use climate model results in view of the scale gap, how does uncertainty propagate from climate to hydrological models, if circulation patterns change—does this decrease/increase floods, how do land-use change and climate variability modify flow pathways and storage, what are the changes in soil structure due to vegetation changes?

More generally, the methods and tools depend on the goals. Management issues associated with soils include the resilience of soil systems, e.g. whether land will be degraded to a point where it will not recover. Management issues associated with vegetation include reforestation strategies, e.g. how best to restore a tropical forest. One possibility, for water quality issues, would be to let forests follow the riparian zone but this may involve time scales of 100 years and more. Modelling may be a platform for combining various sources of information and a vehicle for transferring information to managers and for consensus building among stakeholders. What may help are standardized sets of climate/surface manipulation to be tested in multiple places in a stakeholder relevant way. Clearly, for science–management interaction to become productive, the problem to be solved needs to be a management focused problem on the ground rather than getting a published paper. To truly integrate science with decision making, a primary goal of HELP, it is essential for scientists to work more closely with decision makers and land and water mangers on an on-going basis. In this way, the scientific challenges to ultimately address the management problems can be identified. Research can then be formulated to directly aid in solving the management problems while producing peer-reviewed publications. This process requires a great deal of time and will likely impact the number of publications per unit time of a researcher. The reward is recognition that research results will have a near-term impact on resource and management decisions *versus* the typical slow diffusion of research out of the scientific journals. These journals are rarely read by resource managers and elected decision makers.

DATA SPARSE REGIONS, GENERALIZATION AND POTENTIAL OF TYPOLOGIES

As mentioned above, hydrology is a data limited discipline so, in a sense, all catchments of the world are data sparse. However, in developing countries data density is particularly low. Alternatives to expensive instrumentation are therefore needed. There exist a number of low cost options for measuring hydrological response at various scales. One example at the small catchment scale is simple tubes used as overland flow indicators (Vertessy *et al.*, 2000). At larger scales, low cost monitoring strategies may involve enlistment of volunteers, such as in a successful programme with primary school teachers in Ecuador and the GLOBE programme. Optimizing measurement strategies is another corner stone in addressing the data scarcity issue. Hydrological observatories based on this philosophy have been established, or will soon be established, in a number of countries including the UK and the USA (e.g. by the CUAHSI initiative). Some data types are relatively easy to obtain, so another variant of optimizing the measurement strategy is a prudent choice of the variables to be sampled. If data are scarce, surrogate measures or indices are often extremely useful. Indices are usually designed to represent the main drivers or effects in a particular context with a minimum of information required. Such indices can be based on similarity measures across a landscape focusing on what makes patches of the landscape similar to other patches in terms of hydrological response, what makes aquifers similar to others or, more generally, what makes two catchments similar. Examples of indices include terrain indices to tag processes as a function of landscape position and flash flood guidance indices to tag rainfall intensities needed to produce a flood of a given magnitude (Georgakakos, 2006). Indices can be developed through both the upward and downward approaches. In a downward approach one usually classifies the objects of interest into types or classes to obtain a typology. A typology may help in generalizing findings from experimental catchments and is one method of dealing with the context dependence of hydrology and with data scarcity. A catalogue of catchment types, in terms of flow paths, runoff mechanisms and hydrological regimes would be of great value (Woods, 2002) as would be a worldwide catalogue of aquifer facies geometry and properties (de Marsily *et al.*, 2005).

Data issues and the development of simple indices that could assist in identifying the potential response of low flows and floods to change are therefore of high relevance. The typology approach could be considered instrumental in identifying such indices in diverse hydrological environments. Issues to be addressed include questions as to how climate/rainfall, catchments, aquifers, soils and vegetation can be classified (with a view on floods and low flows) with the help of experimental basins, what processes switch between regimes (in time, spatially), how to give guidance on the necessary regulations given a monitoring network, what variables should be strategically collected that would more directly address impact on hydrological response?

RELATIONSHIP TO HELP INITIATIVE AND OTHER PROGRAMMES

There are a number of avenues for relating the agenda of this working group to HELP and other programmes. First, important links should be established on a personal basis. As noted above, establishing good scientist to manager/decision-maker relationships takes time. Trust must be established and maintained. As a next step, some of the methods developed and/or summarized during the workshops could be applied to a selection of HELP basins. For example, the typologies could be tested in a number of HELP basins as a demonstration exercise keeping data poor areas in mind. In a similar vein, some of the water managers of HELP basins could be involved in the workshops to be held. If this is to occur, the typical scientific workshop format must be modified and tailored to decision-makers. These include representatives of departments of water affairs or EPAs. In particular, the typologies would be of interest from a management perspective because of the potential of simple indices. Winning the acceptance of funding authorities can be greatly assisted by managers' testimonies of the usefulness of tools that have been developed in co-operative research efforts. Some of the HELP sub-basins are research catchments and would hence be a logical starting point for testing novel concepts. Another avenue of interaction with the HELP initiative is to disseminate the proceedings of the workshops to coordinators of HELP basins with a summary to water managers of the respective basins. Another potential contact point is the international flood initiative. This is an interagency initiative that involves UNESCO. The Predictions in Ungauged Basins (PUB) initiative of IAHS has a focus on reducing uncertainty, in particular in ungauged basins (Sivapalan *et al*., 2003). There are a number of growth areas where synergies between PUB and this working group could be exploited. Commonalities are issues of data scarce areas and modelling issues. What sets this group apart from PUB is a focus on change, climate issues and scales including a broader interdisciplinary perspective of management.

SUMMARY

The purpose of each workshop is to summarize the state of the art, to contribute to the planning of research strategies for testing in HELP basins and to further the understanding of land use and climate impact on hydrological extremes. The workshops will be designed to provide a road map of how to address impact issues and to act as a catalyst for motivating communication and targeted research. Some of the topics identified at the working group meeting are closely related to each other and should therefore be dealt with at the same workshop. Issues of change and feedbacks are intimately linked as the type of feedback often controls system dynamics, including their resilience. This could be the topic of a first workshop. Data issues and ways of identifying simple indices of change, e.g. through hydrological typologies, could be the topic of a second workshop. The focus of the third workshop could be on understanding both atmospheric processes and catchment flow processes in the context of impact analyses. The third workshop could hence deal with the effect of climate variability and land-use changes on flow paths in catchments and on their consequences for hydrological extremes. The final workshop could integrate the findings of the previous workshops with a scale focus. Management aspects should be integrated in all workshops.

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