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Management of Mountain Watersheds

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Preface

Mountain catchments are some of the most challenging issues for watershed management. They include areas that are commonly remote, steeply sloping and marginal in many respects: geographical, economic and often socio-political. They are also, often, places that are the targets for the exploitation of natural resources. These resources begin with their scenic and tourist possibilities and continue to include geological resources, water resources and the forests that are their dominant vegetation. Mountain forests, frequently, lie on the front-lines of human development. They compete for space in those sites that are most targeted for human development and share the land with the most exploited and exploitable water resources, mountain rivers and lakes.

Today, mountain watersheds are also giving concern because of the effects of climate change. In strict scientific terms, the effects of these changes are, to date, more anticipated than actually proven. However, climate change contains the potential to be a serious problem because of the relatively extreme vulnerability of these mountain landscapes to catastrophic environmental change.

Formerly, mountain watersheds and their resources were managed often by Government agencies or commercial companies that were mainly oriented to resource development and extraction. The success of watershed management has been that today these lands are more commonly treated as integrated systems for management purposes. Simultaneously, this trend has given an increased voice to the inhabitants of these areas and with that increased voice has come increased responsibilities for environmental management. Increased responsibilities demand better informed communities who are able to understand the process and decisions that have to be taken to conserve and sustain their habitat. This realisation has given new emphasis and importance especially to environmental education in these mountain areas and to education that is constructed to give these communities sufficient understanding to manage their own resource and land use decisions (e.g. Watershed councils in USA).

This volume contains selected papers from the most recent meeting of the European Forestry Commission Working Party on the Management of Mountain Watersheds, which is co-sponsored by the FAO (Food and Agriculture Organisation of the United Nations). The Working Party has a long and distinguished history (described here in the paper by Hofer and Ceci), particularly concentrated now on forest-water relationships in high altitude and latitude regions, and climate change impacts.

This volume is also co-sponsored by the International Association for Headwater Control (NGO founded in 1989), which has sought to bring together the diverse voices of the applied science practitioners, researchers, policy makers and community groups and forge a collective vision of the best management strategies for mountain watersheds around the world.

Josef Krecek
Martin J. Haigh
Thomas Hofer
Eero Kubin

About the Editors

Josef Krecek is the founder and managing Co-Director of the International Association on Headwater Control (IAHC), and former President of the EFC/FAO Working Party on the Management of MountainWatersheds. He teaches courses on Applied Hydrology at the Czech Technical Univesity in Prague, and conducts forest hydrological research on Mountain Waters of the Earthwatch Institute. He is experienced with several international projects in Europe and Asia, and coordinated a number of publications on watershed management and headwater restoration.

Martin J. Haigh is a Co-Director of the International Association on Headwater Control, Senior Fellow of the Higher Education Academy (U.K.), former Vice-president of the World Association of Soil and Water Conservation, and Co-Editor of the *Journal of Geography in Higher Education*. He is also on the Editorial Board of *Asian Journal of Water, Environment and Pollution*, since 2004. He is currently Professor of Geography and University Teaching Fellow at Oxford Brookes University in England. He conducts research into Education for Sustainable Development and Community based Environmental Reconstruction. In 2010, he won the Royal Geographical Society's international 'Taylor & Francis Award' for his contributions to teaching and learning in Higher Education.

Thomas Hofer is Forestry Officer and leader of the Watershed Management and Mountains Team at the Food and Agriculture Organization of the United Nations (FAO). Since 2006, he serves as the secretary of the EFC/FAO Working Party on the Management of Mountain Watersheds. He has vast field project experience in Asia and Central Asia, Eastern Europe, Africa and Latin America. He has coordinated the development of a number of flagship publications on watershed management, sustainable mountain development and forest hydrology.

Eero Kubin is former president of the EFC/FAO Working Party on the Management of Mountain Watersheds, and Management Committee Member of EU COST Action 725. Over 15 years, he served as Director of the Muhos Research Unit of the Finnish Forest Research Institute, and he is leader of long-term research projects on phenology, and environmental aspects of forestry practices. As docent of the Oulu University and Helsinki University he is lecturer on forest ecology and supervisor of several doctoral thesis.

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Part I

Institutional Aspects in Control of Mountain Regions

1

Mission and History of the European Forestry Commission Working Party on the Management of Mountain Watersheds

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The European Forestry Commission Working Party on the Management of Mountain Watersheds, formerly called the Working Party on Torrent Control, Protection from Avalanches and Watershed Management, was established by the European Forestry Commission (EFC) of the Food and Agriculture Organization of the United Nations (FAO) on the occasion of its Third Session on 1 September 1950.

In the course of that session, the Commission considered that soil conservation, restoration and improvement in the plains and in hilly districts constituted an extremely wide problem which required the collaboration of all the actors involved in the rational utilization of soil and water resources. On the other hand, the Commission observed that torrent control and soil restoration in mountainous regions, the importance of which is undeniable, were generally entrusted to the forestry services in European countries. Based on these considerations, the Commission recommended the establishment of a Working Party with the objective to study the technical aspects of torrent control and soil restoration in mountainous regions.

In 1951, at the 4th EFC Session, the Director General of FAO was requested to contact European governments in order to organize in 1952 the first meeting of a Working Party dealing with issues related to torrent control and protection from avalanches. The 1st Session of the "EFC Working Party on Torrent Control, Protection from Avalanches and Watershed Management" was held

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in Nancy, France, in June 1952. The group considered that the mission entrusted to it by the EFC was primarily to study the problems related to the protection from torrents and avalanches of villages, croplands, lines of communication and hydroelectric structures in the densely populated mountain areas of Europe.

In 1970, a seminar on the future orientation of the EFC Working Party was held back-to-back with its 9th Session. At the seminar, it was concluded that the terms of reference of the Working Party had to be enlarged to cover five major points in the following order of priority: torrent control, protection from avalanches, soil and water conservation in mountain regions, mountain land use with a special focus on forest land, and the evaluation of the direct and indirect benefits of mountain watershed management. In view of the broadened mandate, it was decided to call the group "EFC Working Party on the Management of Mountain Watersheds".

The core mission of the Working Party is to bring together member countries of the EFC in order to exchange information on forest and water policies, watershed and risk management practices, to fill knowledge gaps and to follow up on progress made. Its main objectives are to collect information, document technologies, monitor evolution, exchange experiences and discuss progress within mountain ecosystems in view of their sustainable management and conservation. Important areas of consideration are improved mountain livelihood systems and the security of mountain ecosystems, sustainable management with special attention to torrent control, avalanches, risk zoning and mapping, and early warning systems.

The Working Party has played an important role in the follow-up to Agenda 21, supported FAO's role as task manager for Chapter 13 on mountain ecosystems, contributed to the implementation of the recommendations from the International Year of Mountains (2002) and International Year of Freshwater (2003) as well as of the commitments from Warsaw Resolution 2 "Forests and Water" (2007) of the Ministerial Conference on the Protection of Forests in Europe (forest Europe).

The Working Party meets every two years in a host country. Each member country is represented by a focal point who is directly nominated by the relevant ministry. National focal points can be based in academic institutions, research institutes or state technical departments. The dialogue among scientists and government technicians is one of the unique and particular features of the group. The Steering Committee of the Working Party is chaired on a rotational biennial basis by a member country, while the Secretariat is provided by the Forestry Department of FAO. Through the reports and presentations submitted for each session of the Working Party, the member countries and the external observers from different regions and organizations contribute to a flow of information on watershed-related issues. A number of inter-sessional activities ensure that communication and exchange of information between countries continue on a regular basis.

Besides working together with the member countries of the EFC, the Working Party collaborates with many organizations and processes, such as

Forest Europe, UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes, EU Water Framework Directive (WFD), International Union of Forest Research Organizations (IUFRO), UNESCO-IHP-HELP, Mountain Partnership, European Forest Institute (EFI) and its regional offices, UN Water, UN Forum on Forests (UNFF), UN Framework Convention on Climate Change (UNFCCC), UN Convention on Biological Diversity (UNCBD), etc.

In order to continue disseminating up-to-date technical and policy information to different groups of stakeholders, the Working Party must constantly cope with emerging issues of global importance. This is the case of climate change and increased hazards in mountain watersheds. Global warming is affecting vital mountain resources and in turn will negatively impact on the socioeconomic situation of mountain people. The Working Party is engaged in raising awareness on these issues, by assessing and disseminating state-of-the-art knowledge and strategies of adaptation to climate change. Acquainted with the most recent national and international institutional developments and the achievements at the level of field projects as well as with the global development priorities in an exchange with countries beyond Europe, the Working Party always keeps an active reflection alive on the impact of its activities and their relevance to respond to emerging country needs.

The Working Party recently initiated a major review of its mandate and modus operandi, in order to address strategic issues such as the positioning of the group within the evolving institutional landscape in Europe and the appropriateness of the current vision, mission and topics dealt with. The exercise is conducted through a desk review and direct consultations with the focal points of member countries and key partner organizations. The findings of the review show a strong interest from some member countries to expand the mandate of the Working Party to cover forests and water issues and to enhance the focus on disaster risk management in mountains, particularly in the context of climate change. The EFC will consider the outcomes of the review, provide guidance and make recommendations for the future direction of the Working Party. The work of the group will feed into the Strategic Plan of the Integrated Programme of Work on Timber and Forestry of the UNECE Timber Committee (TC) and FAO EFC for the period 2014-2019.

The Working Party, its biennial sessions, the inter-sessional activities, the continuous exchange between professionals from Europe and other regions of the world confronted with similar issues, the passion and dedication of its members to disseminate the findings of their work, all these ingredients are at the base of the present publication. The Working Party provided the opportunity to the numerous authors who contributed to this publication, i.e. experts belonging to different and complementing sectors, to know each other and exchange on a regular basis up-to-date information and case studies. Products like this publication, for which the Working Party provides an institutional framework, represent the added value of a technical, long-standing network such as the EFC Working Party on the Management of Mountain Watersheds.

2

Hydrological Change Management from Headwaters to the Ocean: HydroChange 2008, Kyoto

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1. Introduction

In October, 2008, an international conference in Kyoto, "HydroChange 2008", took on the task of trying to examine hydrological changes and management from the headwaters to the ocean and to integrate the perspectives and concerns of the different scientific, socio-economic and environmental management communities involved in these opposite reaches of the river basin. This ambition created huge problems because of the differences in scale, both geographical and timescale, emphasis – especially the balance between human and natural processes, technical skills, and, because of the march of specialization of each discipline, even technical language. Nevertheless, initiating this dialogue was seen as a necessary step towards the long-term goal of truly integrated watershed management (Fig. 1). It was also seen as a subject true to the spirit of the International Conferences on Headwater Control, which have always sought to integrate the perspectives of the different constituencies that affect the management of watersheds (Haigh and Krecek, 1991; Haigh, 2010). This paper summarizes some of the main outcomes from this initiative.

The conference was organized jointly by Research Institute for Humanity and Nature (RIHN, Japan), International Association of Hydrological Sciences (IAHS) and Global Water System Project (GWSP), and it was co-sponsored

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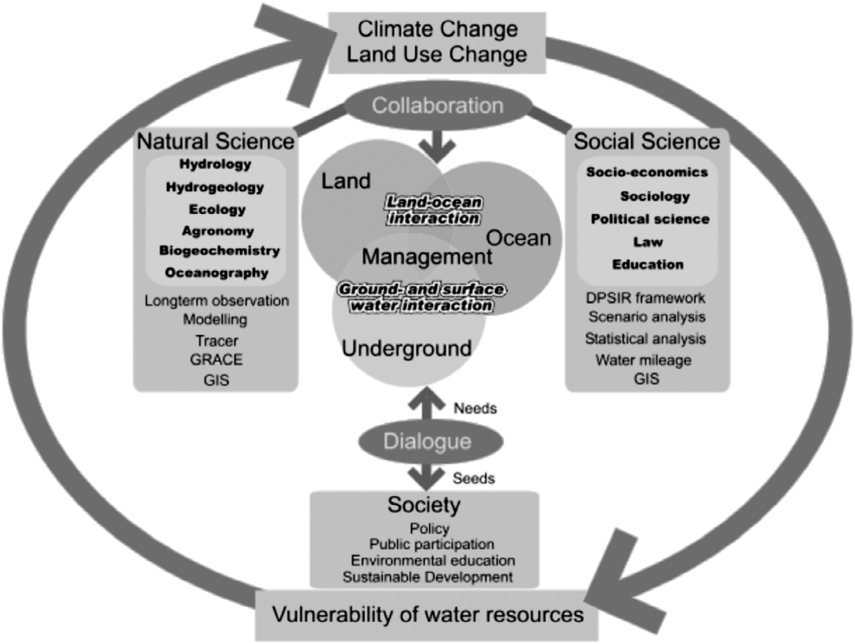

Fig. 1. Holistic approach to hydrological science.

by International Association for Headwater Control (IAHC) and European Observatory of Mountain Forests (EOMF). Some 149 delegates, representing 22 countries, attended and their main technical contributions are published in "*From Headwaters to the Ocean: Hydrological Change and Watershed Management*" (Taniguchi et al., 2009). In particular, this showcases results from RIHN (Research Institute for Humanity and Nature) projects such as *"Human impacts on urban subsurface environments (Project leader: Makoto Taniguchi)"* and *"Yellow River Project (Project leader: Yoshihiro Fukushima)"*, both major multinational initiatives that sought to integrate watershed issues from the headwaters to the ocean. It also carried forward the 'Headwater Control' agendas of the Sixth IAHC Conference in Bergen, Norway, 2005 and the Fifth in Nairobi, Kenya, 2002, which emphasized the need for truly integrated watershed management and for the sustainable management of headwater resources (Beheim et al., 2010; Jansky et al., 2005; Haigh, 2004). This report reviews some key results from the conference proceedings volume, but more importantly, it moves on to describe this meeting's thoughts about what needs to be done in the future.

2. Scope of "HydroChange 2008"

Human activities and climate change are increasing the vulnerability of water resources. However, examining and managing hydrological change is

Table 1. HydroChange 2008: Conference Sessions

Session	*Key topics*
1.	Land-atmosphere interaction
2.	Headwater environment: impacts of climate change and human intervention
3.	Strategic planning and environmental assessments of activities in headwater areas
4.	Environmental education for sustainable development: the role of mountain and headwater landscapes
5.	Hydrological models in support of integrated water resources management
6.	Groundwater-surface water interaction
7.	Remote sensing for measuring water balance, hydrodynamics and hydrological processes
8.	Interaction between the groundwater resources and ecosystems
9.	Socio-economic analysis and monitoring of vulnerable water resource
10.	Reconstruction of human impacts on the surface and subsurface environments during past 100 years
11.	Land-ocean Interaction

Further details are available on the official web site: http://www.chikyu.ac.jp/HC_2008/index.htm

complicated because of the complex interactions between natural climate fluctuation, global warming and human activities, especially changes in land utilization. The effects of these changes extend from the margins of every river basin to the ocean through coastal water exchanges (Fig. 1). This "HydroChange 2008" conference aimed to explore these patterns of interaction and the way they may change because of future climate change and increasing human pressure. Its key topics included land-atmosphere interaction, land-ocean interaction, groundwater-surface water interaction, and the diagnosis and management of environmental change, especially in headwater, estuarine, coastal and offshore environments (Table 1). Its papers included many natural scientific studies as well as, socio-ecological analyses, environmental management, besides social and policy related issues. The approach was interdisciplinary, problem-solving and aimed to raise consciousness about the issues facing integrated water management in the face of accelerating anthropogenic and climatic change.

After three days of presentations and discussions, delegates joined together to seek out the main conclusions and messages from their experience. These plenary discussions were led by Session chairs, who opened each discussion with their summary of the findings from their session.

3. Discussions and Findings

Sessions 1 and 7 concerned Land-Atmosphere Interactions and Remote Sensing. From Australia, CSIRO's Dr Helen Cleugh emphasized the role of land use change in changing the energy balance at the land surface, which had consequences that extended up into the atmosphere as far as the boundary layer and whose effects included storm generation. As ever, such matters complicated the debate about climate change. Several researchers had identified secular changes in precipitation, but these could as easily be the result of land use change (Tamai et al., 2009) as climate change (He et al., 2009). One novelty was a study that considered the atmospheric role of underground cavities (Weisbrod et al., 2009). Session 7 papers dealt with applications, especially of GRACE satellite data, to the study of evapo-transpiration, drought (Hasegawa et al., 2009) and to shallow aquifer water storage (Yamamoto et al., 2009). A key problem of the modelling was linking data sources effectively across different geographical scales. However, MODIS and AVHRR satellite data proved useful for estimating the amount of vegetation and for detecting patterns of vegetational change and their relation to environment factors.

The main IAHC contribution to the "7th International Conference on Headwater Control" was contained by Sessions 2, 3 and 4. Session 2 focussed on environmental change in headwater environments and reported results from an array of long-term, intensive field studies, most of which carried discussion beyond detailed analyses of long-term hydrological change into management strategies for combating the deterioration of water quality and resource. The effects of human actions were more apparent than the signals of climate change. However, the balance of evidence and opinion had shifted noticeably towards the latter since the conferences in Bergen and Nairobi (Beheim et al., 2010; Jansky et al., 2005). Here, the key topics were: runoff generation in headwaters, especially the evaluation of significant influences in the headwater environment upon stream flow and groundwater recharge (e.g., Katsuyama et al., 2009; Oda et al., 2009); the role of environmental change in increasing the incidence of natural hazards such as debris flows (Marchi et al., 2009); and impacts of forest stands and forestry management practices on runoff quality and volume (Kubin and Krecek, 2009; Fukushima et al., 2009). An array of important and detailed empirical studies of soil hydraulic properties demonstrated the ways that environmental changes, both natural (Liang et al., 2009) and/or anthropogenic (Hayashi et al., 2009), control runoff generation processes in small catchments. Isotope and chemical tracers were shown to be powerful tools for exploring these hydrological processes (Katsuyama et al., 2009; Oda et al., 2009). As the IAHC's Dr Josef Krecek noted, long-term monitoring was critical to understanding and clarifying the environmental response to processes such as runoff intensification, accelerated soil erosion and weathering, greater landslide and debris flow activity, and acid atmospheric deposition, as well as purely anthropogenic factors such as industrial pollution, resource exploitation and development, which remained problems in headwater areas (Krecek et al., 2009). The new evidence confirmed that both natural and near-natural forest soils helped stabilize headwater hydrology and that forest management practices play a powerful role in headwater environments for both good and ill. It also demonstrated that there was a need to improve the link between science and civil society to avoid further problems due to bad environmental management policy.

Environmental management policy and the communication of hydrological understanding through education in the community were the subjects of Sessions 3 and 4. Dr Takahiro Endo, speaking for Research Institute for Humanity and Nature (RIHN), reflected on the policy frameworks that guided environmental management in watersheds, on management intervention options that included hard engineering, soft engineering, land use regulation and institutional change, and asked the key question: how to pay? Two possibilities were discussed: first – the concept of local currencies, funded by the community through discounting in local businesses, which could be used to support environmental projects, and second – targeted taxes, where communities, howsoever defined, paid taxes that were specific for particular watershed functions, such as flood control and landslide prevention (Endo, 2009). Another paper discussed the problem of providing adequate training for future environmental managers and advocated field-based problem-based learning as an important, if not wholly unproblematic, way ahead (Haigh, 2009). A case study from Brazil described an excellent and original example of good practice in community education. This concerned a programme that linked research, environmental management and education through a system of School Catchments, which were operated by secondary schools, but which were integrated within both an educational programme and a system of water and flood hazard management required for municipal and research purposes (Kobiyama et al., 2009). Discussion focussed on an unresolved debate about the balance of emphasis and responsibility in environment policies formulation. Endo showed the effectiveness and limits of governmental action in environment management. Haigh and Kobiyama pointed out usefulness, but also limitations, of grass-rooted, community-based management. However, it was agreed that the bottom-up and top-down approaches could be combined as “two wheels” to carry forward better environment management practice and that realizing such better management structures at all levels will be an important topic for future research.

The main contribution from the International Association of Hydrological Sciences reflected the IAHS commitment to hydrological modelling, notionally in support of integrated watershed management. This has been a controversial topic at many of the international conferences on headwater control, where the limitations of research based on simulation rather than empirical observation have been much debated. Here, the large contingent of 18 papers received a critical review from Professor Vijay Singh (Texas A and M University) (Singh, 2009). He noted that of the 18 papers presented, only two actually dealt with integrated watershed modelling. Six presented models, often of some technical novelty, but, he argued, there was a need to go beyond mere models. In five of these cases, either the underlying scientific foundation was weak or the issues of error and model reliability were missing. In fact, only one paper tried to integrate its hydrological model with the social system (Wang et al., 2009), this effort was commended.

As in previous meetings, 5-6 papers struggled to evaluate the impacts of climate change (e.g., Coulibaly, 2009; Fujihara et al., 2009). Here, quality control and ground-truthing presented major problems.

Professor Singh concluded that the sessions had sign-posted three areas that needed future attention. First, there was a need to do more to recognize the needs of the model user. Second, much more work was needed to integrate the social, institutional and legal frameworks with the physical hydrological management models. Third, there was a need to go beyond the scientific comfort zone and both work and communicate with society at large.

Evaluation of human impacts during the last century was the focus of a diverse group of papers. These displayed the divides between the geophysical (e.g., Miyakoshi et al., 2009), hydrological (Iizumi et al., 2009), geographical (e.g., Yamashita, 2009), and socio-economic (e.g., Overton and Doody, 2009) approaches. One novelty was a paper that described an urban heat island effect in the groundwaters beneath part of the Tokyo conurbation (Miyakoshi et al., 2009). This paper was based on numerical analyses of subsurface temperature distribution in boreholes near Tokyo. Studies with a socio-economic emphasis tackled historical changes of flood risk and sewage system following urbanization. Several papers engaged Geographical Information Systems and employed statistical analyses but there remained the need for more widely integrated approaches.

Another session addressed socio-economic models and the management of threatened water resources. Reviewed by Professor Felino Lansignan (University of the Philippines) these presentations dealt with the problems of the allocation and multiple usage of water resources (e.g. Wang et al., 2009; Aoki et al., 2009; Jago-on and Kaneko, 2009), the impacts of environmental change whether due to human (Banchongphanith and Kaneko, 2009; Onishi et al., 2009) or climate (Palanisami et al., 2009) change induced drivers, and the development of indices for the evaluation of water resource stress (Lansigan, 2009). These studies employed an array of techniques including computer simulation, statistical analysis and scenario analysis. Discussions highlighted the vulnerability of water resources and emphasized the need for better development of technologies for water use efficiency. The applicability of the DPSIR (Driving forces, Pressures, State of the environment, Impacts and Responses) framework in the integrated assessment of vulnerability of water resources was discussed. Among the many opportunities and challenges for future research, collaboration across international and disciplinary boundaries provided a major way ahead.

The issue of ground and surface water interactions, the focus of Sessions 6 and 8, had been highlighted for urgent attention at the 6th IAHC Conference in Bergen, 2005. Dr Takeo Onishi (RIHN, Kyoto) noted several valuable attempts to integrate subsurface and surface flows in computer simulation (Nagano et al., 2009; Yamanaka and Wakui, 2009) as well as valuable papers that evaluated the role of deep bedrock groundwater effects on runoff in headwaters (Kosugi et al., 2009), and of shallow groundwater on dissolved iron production in wetlands (Onishi et al., 2009). This session, again, emphasized the need for interdisciplinary collaborative researches among Hydrology, Hydrogeology, Ecology, Agronomy, Socio-economics etc. to construct a broader understanding of the interactions between ground water and surface water processes and mechanisms, especially in key locations such as headwaters, wetlands, forests, irrigation areas and urban areas. Dr Yu Umezawa (Nagasaki University) saw the Session 8 papers setting climate change and human action side by side to look at the effects of environmental change on groundwater storage, salinization (Mekpruksawong et al., 2009) and contaminant transport. Problems were expressed in terms of factors influencing the shift or deterioration of natural vegetation (Doody and Overton, 2009), croplands (Kume et al., 2009), the species composition of benthic fauna and bacteria, and biogeochemical cycles. The main conclusion was the need for modelling based on intensive observation with improved monitoring techniques, as well as better water management policy, regulation and engineering.

A major attempt to integrate the analysis of hydrological change from the headwaters to the ocean, through both direct observation and modelling, was the focus of the final session, reviewed by Professor William C, Burnett (Florida State University). This session tackled land-ocean interactions head-on as well as the difficult interface between field observations and modelling. A novel feature was extended discussion of the submarine groundwater discharge (Taniguchi et al., 2009; Katsuki et al., 2009) and the role it played in offshore water quality (Peterson et al., 2009; Saito et al., 2009) and the observation of blooms of invasive macroalgae (Umezawa et al., 2009). The session opened up the possibilities for new and fruitful cooperation between oceanographers and hydrologists.

Concluding, the organizers reflected upon the degree to which the Conference had succeeded in its aims to integrate the concerns of watershed management from the headwaters to the ocean. They recognized that, while discussion of main-channel hydrologies had been underdeveloped in the meeting, the conference had done much to alert the extremely specialized scientific communities to work in sister areas.

4. Toward Holistic Approach to Hydrological Science

Today, society faces major problems from the vulnerability of water resources for drinking, irrigation, industry etc. Natural and social scientists need to define and predict explicitly the present and future condition of the water resources, and how to manage them appropriately. Hooper (2009) points out that each hydrologist has pursued researches with a different focus and each study defines different frontiers. Most studies describe subject areas, but few illuminate similarities or differences in the intellectual basis of their research. Hooper (2009) proposes that future researchers should recognize the three dimensions of the hydrologic cycle: vertical (boundary layer to bedrock), down-slope (ridge to stream), and down-valley (headwater to ocean). This framework provides a context for a key conclusion from this event, which is the need to define "Ground water-Surface water interaction" and "Land-Ocean interaction" (Fig. 1). To understand and manage properly the complicated hydrologic and other related phenomena within the wide range of land use such as forest, wetland, irrigation area, urban, coastal and so forth, it will be necessary to collaborate and integrate more effectively across many specialized disciplines of hydrogeology, ecology, agronomy, oceanography, biogeochemistry as well as hydrology. Tracers, remote sensing and satellite gravity mission GRACE, for example, are valuable tools for fostering better understanding of these interactions between ground water and surface water and/or land and ocean while GIS proves an increasingly effective way to analyze and interpret these results. Long-term, intensive observations and modelling studies are vital contributions for understanding and predicting the course of environmental change and must be protected from short term economic and political threats.

Hitherto, natural resource management, in general, has been conducted in a fragmented way; i.e. surface water is usually subject to public control, while ground water is regarded as private property of land owners, or land use policy does not pay attention to its impact to the ocean. The results reported in this conference challenge policy-makers to rethink their traditional natural resource management policies. However, the lines of communication between scientists and policy makers will have to be much improved before many of these scientific findings can or will be incorporated into more effective actual policies. While scenario analysis, water mileage, and the DPSIR framework may contribute to this goal, more systematic research on environmental education and communication as well as more interdisciplinary studies involving economists and political scientists should be developed. Simultaneously, the question of whether the research programmes that scholars ask their wider society to fund are really those that serve the best interests and needs of that society must be addressed more rigorously.

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3

Water Management Adaptation Strategies for Land Use Changes and Increased Climate Variability in Mountain Communities in Western Canada

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1. Introduction

The Columbia River in Western North America originates in the Rocky Mountains of British Columbia, Canada and flows into the Pacific Ocean in Oregon. The river is 2000 km long, has the highest vertical gradient of any major rivers in North America and covers an area of 670,000 km^2. There are 14 major hydropower stations on the main stem of the river and more than 300 smaller stations distributed throughout the basin that provide the majority of the electricity for the Pacific North-West. The Canadian portion of the basin covers only 15% of the total watershed area but provides approximately 40% of the water that flows downstream. Fifty percent of the electricity consumed by the 4.3 million people in British Columbia is produced in the Canadian portion of the Columbia Basin. More than 80% of the Canadian headwater area is forested and under alpine cover and the river system is dominated by snowmelt and selective contributions from glaciers.

There are 25 mountain communities in the Canadian portion of the basin and all are experiencing changes in land use and increased climatic variability. There is an urgent need for these communities to develop adaptation strategies in order to be able to cope with emerging water resource management problems relating to increased flooding, water shortages, terrain instabilities, sediment transport and associated water quality issues. Most communities rely on surface water in forested watersheds for their domestic water supplies and have poor

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and aging infrastructure systems in place. There is a general lack of water accounting because water metering is largely absent and few communities have quantitative information on their supplies and use of water. There is now a growing awareness that water supplies are under pressure because of increased climatic variability, hydrological impacts due to land use changes in the forest ecosystem and the need to maintain sufficient water for ecosystem services.

The aim of this paper is to document what the impact of climate change and land use activities are on the aquatic ecosystems and how communities must initiate source water protection strategies to assure water supplies are sustainable. The threats to the forested environments from increased temperatures, diseases, and fire is resulting in increased risk for community water supplies.

2. Increased Climatic Uncertainties

Climate models for the Columbia Basin suggest that warmer temperatures, highly uncertain rainfall, earlier snowmelt, more rain on snow event, accelerated glacial melt, and shifting streamflow pattern, with earlier and higher peakflow and lower baseflow in late summer will be the main impacts of climate change (Murdock et al., 2006; Hamlet et al., 2005; Stewart et al., 2005).

2.1 Evidence of Increased Climatic Variability

There is ample evidence that the average temperatures have increased by about 1.1^{o}C over the past 100 years (Murdock et al., 2006). More important is the more rapid increase in minimum temperatures in the winter (1.6^{o}C), particularly warmer night temperatures. There is also evidence that temperature increases are proportionally higher at higher elevation and this is of significant concern for the maintenance of glaciers and the snow melt regime (Redmond and Abatzoglou, 2007). Climate models project annual and winter minimum temperature to increase by 1.4-3.6^{o}C by 2050.

There are 14 glaciers in the basin and the majority of streams are snow dominated which means that increased winter temperatures will lead to potentially more rain than snow and earlier melting of snow in the spring. The historic data shows a 3% increase per decade of total precipitation but an increase of 36% in rain while the snow component has decreased by 6%. Snow cover data published (Mote et al., 2005; Hamlet, 2011) clearly shows a significant decline in April 1 snow depth over the past 60 years for most of the watersheds in the Pacific North-West. This means that peakflow in most streams will seasonally advance by 2-4 weeks and this results in extended summer low flows (Hamlet, 2011). Higher summer temperature, lower summer precipitation, and lower runoff will lead to more frequent drought affecting fish, water supplies, and recreation. Glaciers which contribute 10-20% to the annual flow and up to 50% of summer flow to the stream can make a significant contribution to keep summer water temperatures low and tolerable for most