Mountain Ecohydrology: Issues and Challenges[1]

H. Lang
Department of Geography, Hydrology Section, Swiss Federal Institute of Technology Zurich, Winterthurerstr. 190, CH-8057, Zurich, Switzerland

The Global Perspective of Mountain Hydrology

In the interaction of the earth's land surfaces with the atmosphere, high mountain areas play a most decisive role in the areal distribution of precipitation and hence of water resources on the continents. As a result of the forced orographic lifting of advective air masses or of the enhanced convective activity in the elevated source areas of sensible heat and water vapour, most of the earth's mountain regions are extraordinarily rich in water resources, and in many of the world's large river systems the water flow originates mainly from high mountain areas which provide a reliable water supply for our societies. Moreover, in the high mountain elevations an increasing amount of precipitation is accumulated as temporary snow cover or, above the climatic snow-line, forms perennial snowfields and glaciers. This naturally stored water feeds the river flow with meltwater, often during the same season that purely rainfed rivers are at minimum flow.

The Challenge of Mountain Research

In spite of this universally significant role of high mountain water resources, our scientific knowledge about mountain hydrology is still comparatively poor, given, for example, our ignorance of the real quantities of precipitation and evaporation in the high mountain regions. We all know the reasons for this: high mountainous terrain is extremly difficult terrain in every sense.

1) Climatic and living conditions, accessibility, natural hazards, and remoteness are the reasons for lack of observation networks and data.
2) The great spatial variability, including altitudinal gradients of terrain, vegetation and rock surfaces, soil, underground water, snow and ice conditions, and all meteorological variables, altogether pose numerous problems to be solved in hydrological modelling of mountain river basins.

It is worthwhile to remind ourselves here that in spite of the difficult general - conditions in high mountain areas, remarkable efforts have been made in various regions and on various topics. The strong development of hydropower and irrigation schemes in some high mountain areas has promoted hydrological networks and investigations in those regions since before the middle of this century (Luetschg 1926; Lang 1988). In the context of these activities, an increasing interest in snow cover accumulation and melt evolved which stimulated snow hydrological research work, particularly in North America and in the European Alps

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(U.S. Army 1956; Bader et al. 1954). Considerable scientific and practical attention has been paid to glaciers and the variations they undergo for more than one hundred years now. Spectacular glacier advances and retreats, outbursts of glacier dammed lakes, and the fascination of ice streams, together with the development of mountaineering, have provided a continuous basis for long-term observations and research on glaciers as parts of the hydrological cycle.

The Gap between Knowledge and the Need for It

However, in view of the great hydrological importance of mountain regions, our information and knowledge of the different components and processes in the hydrological system of mountain regions are still very incomplete and fragmentary. There is above all very great uncertainty about the real temporal/areal distribution of precipitation in the high altitude zones; in most cases the only information available is that derived from valley stations. Because of the complex influence of mountain topography on the air mass circulation over the whole range from large to small spatial scales, there is also great uncertainty about the vertical gradients in precipitation. As a result, there is often no reliable basis for estimating the atmospheric water input into our mountain systems. The few high-altitude precipitation gauges available in some mountainous regions are, in addition, strongly affected by the systematic wind-induced error, and in most cases there is no database for applying reliable corrections. Many other water processes are similarly not sufficiently understood, such as the role of soils and non-vegetated areas, the effect of the various vegetation belts, and the role of surface and subsurface flow in the generation of floods.

Challenges and Activities

The uncertainties about precipitation are reflected in a corresponding lack of information about evaporation (including evapotranspiration) in the high mountain ranges. Because of the high energy turnover in the generation of atmospheric precipitation and in the evaporative processes at land surfaces, these gaps in our knowledge have serious consequences not only for hydrological investigations and water resource assessments but also for the accuracy of global general circulation model simulations of climatic conditions.

The increasing awareness of the importance of water-related land surface processes in the development of climate models, meteorological numerical forecasting models, and ecosystem models has stimulated national and international scientific activities such as the initiation of the Global Energy and Water Cycle Experiments (GEWEX). Up to now, in spite of its extraordinary importance, no high mountain GEWEX project has yet been carried out. However, it should be mentioned that the so-called Himalayan Experiment (HIMEX 1995) is under discussion, and the Mesoscale Alpine Programme (MAP 1996) in the European Alps is in the concrete planning stage. Both projects envisage incorporating an assessment of the hydrological processes, including vegetation cover and snow and ice, and coupling the hydrological models to the atmospheric model components. A strong international initiative for integrative research was undertaken by the International Geosphere - Biosphere Programme (IGBP)/International Council of

Scientific Unions (ICSU) core project, Biospheric Aspects of the Hydrological Cycle (BAHC) and its workshops on Climate-Hydrology-Ecosystems Interrelations in Mountainous Regions (CHESMO 1994). As an outcome of the first CHESMO seminar, held in 1993 in St Moritz, recommendations have been formulated.

CHESMO Recommendations

1. The intensification, coupling, and focussing of research activities in mountainous regions is urgently needed to achieve the required progress in modelling the interrelations between climate, hydrology, and ecosystems, as well as the effects of climate changes and other impacts on natural resources (soils, water resources, ecosystems) on different spatial and temporal scales.
2. This research needs to be increasingly integrative and multidisciplinary.
3. Special emphasis should be given to development of the improved measuring techniques adequate for the harsh extreme conditions in the mountains (ice, strong winds, heavy rainfall, etc) and to advanced network design taking into account the distinct gradients in meteorological and hydrological conditions across mountain ranges (dependent on elevation, exposure, etc).
4. Maximum possible use should be made of remote sensing (from space or on the ground, e.g., radar) in order to better assess areal patterns of important characteristics, especially precipitation (rainfall and snow water equivalent).
5. The planning and long-term operation of a few carefully selected multidisciplinary experimental research basins (approximately 10^4 km^2 in area) with embedded smaller, well-equipped sub-basins, and supersites at critical locations (nested basin approach) is considered particularly important.
6. Special attention should also be given to the study of human impacts on natural resources (water, soil, vegetation, etc.) and the delicate balance between ecosystem productivity, applied practices using these resources, and expected climate change.

Large versus Small Observation and Research Projects

How should we reduce the aforementioned gaps in our knowledge of ecohydrological processes and water resources in high mountain areas? Given the general limitations of available funds for observation networks and for scientific research projects, it is obvious that much effort should be dedicated to the careful design and coordination of projects, that priorities are defined concerning problems, which may vary considerably from region to region, and that thought is given to the efficiency of certain methods. For example, the poor knowledge on precipitation at high elevations is a permanent challenge to the extension of precipitation gauge networks. However, we all know how difficult it is to maintain such a network, including the cost to do so. In addition, such data are often very unreliable because of the basic problems of precipitation measurements. From the present point of view and state of the art, it may, under such circumstances, be best to solve the problem by model computations of the evapotranspiration on the basis of a digital terrain model and remotely-sensed land-surface and soil data. Together with runoff data from a few well-maintained river flow gauging stations, the determination of precipitation by means of the water balance equation will certainly provide more reliable information on the real precipitation in many mountain river basins. And by using model computations together with only a few reliable ground-based sources of information and measurements, the spatial distribution of precipitation may be suffiiciently determined. Of course such an approach will not solve the requirements for real-time operational forecasting, but in many cases this may be the more practical way.

Looking Forward

The question of what research projects and approaches should preferably be conducted cannot generally be answered. We can afford only a few large projects based on internationally coordinated efforts and probably a very few of these big experiments are sufficient. They will help to improve the large- and mesoscale models. Of equal importance are the smaller projects on the small-scale processes in the soil-plant-atmosphere water system as it relates to mountains. Combined with the larger-scaled projects and with the advanced development of physically-based models and, last but not least, with a reasonable minimum density of monitoring and observation sites, our understanding of the ecohydrology of high mountain areas will progress.

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