Predicting Global Change Impacts on Mountain Hydrology and Ecology: Integrated Catchment Hydrology / Altitudinal Gradient Studies

Workshop Report

The International Geosphere-Biosphere Programme (IGBP): A Study of Global Change of the International Council of Scientific Unions (ICSU)
Stockholm, Sweden
Predicting Global Change Impacts on Mountain Hydrology and Ecology: Integrated Catchment Hydrology / Altitudinal Gradient Studies

Workshop Report

Documentation Resulting from an International Workshop
Kathmandu, Nepal
30 March - 2 April 1996

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**Workshop Report**

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Cover Photograph: Mountain landscape in the Val d’Anniviers, Switzerland, showing the interplay between human land use (pastures, settlements), vegetation structure (subalpine conifer forests) and hydrology (glaciers and streams). (Photo. H. Bugmann).

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Preface

We are pleased to present this document resulting from a workshop on IGBP mountain research issues held at the International Centre for Integrated Mountain Development in Kathmandu, Nepal, from 30 March to 2 April 1996. Thirty-four participants attended the workshop: Fourteen from the Global Change System for Analysis, Research and Training (START) South Asian Committee (SASCOM) region, fourteen from Europe, four from the US, and one from Africa (see Appendix II). The SASCOM office in New Delhi was represented by Dr. S.C. Majumdar, United Nations Educational, Scientific and Cultural Organization (UNESCO) by Dr. L.A. Mandalia from the regional office in New Delhi, and World Meteorological Organization (WMO) by Dr. Z. Kundzewicz from the Geneva headquarters.

After introductory presentations by the workshop conveners, oral presentations by nearly all participants (see Appendix III), and extended discussions, the workshop participants established three working groups and two sub-groups to prepare written contributions to an “Proposed Mountain Workplan”, including a draft proposal for specific Activities and Tasks (See Appendix I). The following themes were addressed by the working groups:

1. “Role of ecology and hydrology for the sustainable development in mountain regions” (the “human dimensions”)
2. “Coupled ecological and hydrological studies along altitudinal gradients in mountain regions”, with a sub-group dealing with the “Assessment of the spatial distribution pattern of basic water balance components”
3. “Impacts of global change on the ecology and hydrology in mountain regions”, with a sub-group on the “Identification of global change impacts on hydrology and ecology in high mountain areas”.

The chairs and rapporteurs of the working groups formed the Editorial Board for the main text of this documentation.

The main results of the workshop were presented by the primary convener of the workshop, A. Becker, at a special meeting at the IGBP Congress in Bad Münstereifel, Germany, from 18 to 22 April 1996. A number of comments and recommendations were given concerning how to proceed. These are summarized in the Minutes of this
meeting, which are included in Appendix IV. As agreed in the meeting, Professor Bruno Messerli, of the IGBP Past Global Changes (PAGES) Programme Element, on behalf of the Biospheric Aspects of the Hydrological Cycle Scientific Steering Committee (BAHC SSC), provided information on the interest and possible contribution of PAGES to the Proposed Mountain Workplan. It is included as Appendix V.

On the basis of the work described here, it is suggested that an IGBP project on “Global Change Issues in Mountain Regions” should be initiated where, in addition to Biospheric Aspects of the Hydrological Cycle (BAHC), Global Change and Terrestrial Ecosystems (GCTE) and Global Change System for Analysis Research and Training (START), also Past Global Changes (PAGES) and Land-Use/Cover Change (LUCC) will participate.

The editors and the editorial board prepared this document based on written and oral contributions of the workshop participants listed in Appendix II of this document. Additional invaluable input was provided by Hank Shugart (Charlottesville, USA), Will Steffen (Canberra, Australia) and Ian Woodward (Sheffield, UK).

The Kathmandu workshop was organized jointly by the BAHC International Project Office (IPO) at the Potsdam Institute for Climate Impact Research, Potsdam, Germany, and the GCTE IPO at the Division of Wildlife and Ecology, Commonwealth Scientific and Industrial Research Organization (CSIRO), Canberra, Australia, in cooperation with the International Centre for Integrated Mountain Development (ICIMOD), Kathmandu.

The workshop was sponsored by: IGBP Secretariat, Stockholm, Sweden; German Federal Ministry for Education, Research and Technology (BMBF), Bonn, Germany; START Secretariat, Washington, D.C., USA; and the Swiss Academy of Natural Sciences (SANW), Bern, Switzerland.

Alfred Becker                            Harald Bugmann
Introduction

Mountain regions make up one-fifth of the Earth’s land surface, and they have a considerable role and global importance as environmental resources. For example, the Himalaya is the source of eight rivers draining almost 5% of the Earth’s land area and generating around 25% of the sediment load to the world oceans (Bandyopadhyay et al. 1997). Globally, mountain regions provide water to about 50% of the world’s population both in the mountains themselves and, more importantly, also in many downstream lowlands (Bandyopadhyay et al. 1997). Mountains are home to a substantial portion of the planet’s diversity of species and ecosystems. Finally, all over the world expanding economic pressures are degrading mountain ecosystems while confronting mountain peoples with increasing poverty, cultural assimilation, and political disempowerment (e.g., Stone 1992, Messerli and Ives 1997).

Global Change is a multi-faceted issue, incorporating direct and indirect effects of human activity. Direct effects include land use conversion and intensification, and emissions of pollutants (e.g., NOx, O3, heavy metals, acids). Indirect effects include atmospheric change associated with increase in trace gas emissions and stratospheric ozone degradation, which subsequently have an impact on climate and UV-B radiation. Some of the indirect effects can only or best be studied in high mountains; these systems are among the few where direct human impacts are not so pronounced or are absent entirely.

Therefore mountain regions present unique challenges to and opportunities for Global Change research. In particular, the steep slopes found in these regions give rise to some of the sharpest environmental gradients found on Earth’s land surface. The characteristics of these gradients include:

- Rapid and systematic changes in climatic parameters (especially temperature and precipitation) over very short distances
- Sharp climatic changes independent of photoperiod (length of daylight) and often of soil type (thus, they complement high latitude gradients where photoperiod and soil type often change)
- Systematic, often monotonous variations in slope angle, aspect and exposure
- Greatly enhanced direct runoff and erosion, strongly influencing overall hydrology
• Systematic variation of other environmental parameters (e.g., soil depth and structure, CO₂, UV-B) with elevation.

Relevant terms which are important in this context are defined in Box 1. The listed characteristics make mountain regions with their sharp topographical gradients:

• Particularly valuable in providing basic understanding of hydrological and ecological responses to global change
• Particularly susceptible to the impacts of a rapidly changing climate, often coupled with land use change pressures
• Likely to be the areas where signals of climate change impacts on the biosphere can be detected and studied.

To assess cause-effect relationships and provide inputs for modelling, not only passive observations and measurements of processes are required, but also manipulative experiments. The use of such experiments along altitudinal gradients is especially powerful. Gradients of the physical environment and functional groups of biota (plants, animals and microbes) occur across relatively short altitudinal gradients, and provide a tool for assessing the interacting effects of environmental and biotic constraints on ecosystem response to global change. Altitudinal gradients allow us to examine the correlation between environmental variability and biotic patterns, which can be used as a framework to design conceptual and analytical models to predict the distribution of the biota, which can be subsequently validated using manipulative experiments. In turn, natural variation in biodiversity occurs along altitudinal gradients, allowing evaluation of its effects on ecological and hydrological processes. Several environmentally sensitive boundaries, both ecological (i.e., ecotones) and hydrological (snow/ice/land, permafrost/thawed ground) occur along altitudinal gradients, which may be useful for monitoring global change. Lastly, a spatially nested design of measurements, manipulation and modelling along altitudinal gradients will facilitate a scaling approach for addressing potential landscape responses to global change.

In addition, there are two developments which enhance the potential value of global change research in mountain regions: First, there is already a significant number of active or planned altitudinal gradient studies that are addressing global change issues, and could be strong contributors to a coordinated IGBP study, for example the U.S. National Science Foundation (NSF) Long-Term Ecological Research (LTER) Network. Second, the remotely sensed images now becoming available from satellites with ever-improving instruments, and also through the declassification of military information obtained during the cold war, provide for the first time very high-resolution pictures of mountain regions that can support global change research based on altitudinal gradients and mountain catchments. When coupled with ground-based data gathered from existing studies, these high resolution data will provide an excellent platform on which to build further experimental and observational studies and support model development.
Box 1

Definitions.

**Mountain Region**
Mountain regions are characterized by:

- Substantial gradients in environmental characteristics due to rapid and sharp altitudinal gradients, leading to
- Specific dynamics of hydrological processes with important positive and negative consequences (high water yield due to high amounts of precipitation, disastrous floods with soil losses resulting, *e.g.*, in high sediment loads in rivers)
- Distinct altitude-specific pattern ("zonation") of vegetation structure, composition and functioning.

Areas like the Himalayas, the Rocky Mountains or the European Alps, with glaciers and long-lasting snow cover at higher altitudes and with well-developed vegetation cover and human settlement on lower slopes and in the valleys, most typically represent "mountain regions", but lower mountain ranges should not be excluded if they fulfil the above three criteria.

**Altitudinal Gradient**
An altitudinal gradient represents a large change in altitude over a short distance associated with a significant climatic gradient. Altitudinal gradient studies in the present context should encompass a change of environmental conditions as it typically occurs vertically over about 1000 m at a minimum. Gradient studies should not be restricted to smaller scale local studies aimed at individual ecosystems. In addition, the gradients will normally cover the transition from forests through alpine vegetation to open vegetation and the snow line.

**Gradient vs. Transect**
A gradient is a continuous line in an environmental parameter space, *i.e.*, a continuous change of a parameter such as temperature, precipitation, or nutrient status of the soil. It does not have to be continuous in geographical space but can be a composite of several transects.

A transect is a continuous line in geographical space. Although transects often are set up as straight lines, they can also be curvilinear. Typically, a transect also represents an environmental gradient.

**Alpine**
The zone above the upper (cold) treeline characterized by short, closed vegetation, *i.e.*, mostly tundra.
Recent International Research Initiatives

Because of their unique characteristics and opportunities, various aspects of global change interactions with mountainous regions have already triggered significant activity within the international research community. For example, within the IGBP the programme elements BAHC and GCTE have developed a number of activities related to mountainous regions (e.g., Becker et al. 1994, Chalise and Khanal 1996). On the other hand, the START system of the IHDP, IGBP and World Climate Research Programme (WCRP) has established regional networks and centres in several parts of the world, including those where global change issues in mountain regions form an essential element in the research agenda and in training. Moreover, several other research programmes on environmental problems in mountain regions that are relevant to Global Change research have been initiated and are implemented under the auspices of other organisations such as UNESCO’s International Hydrological Programme (IHP) and Man and the Biosphere Programme (MAB, Price 1995), the European Union (EU, Price 1995), the U.S. Environmental Protection Agency, and regional authorities (e.g., Ives and Messerli 1990, Cernusca 1989).

All these developments are related to and confirm the importance of Chapter 13 of Agenda 21, endorsed by the United Nations Conference on Environment and Development (UNCED) entitled “Managing Fragile Ecosystems - Sustainable Mountain Development”, the so-called “Mountain Agenda”, which also supports the need for research (cf. Ives et al. 1997). There, two programme areas are formulated that are directly related to BAHC’s and GCTE’s interests, and they deserve particular attention: First: generating and strengthening the knowledge about the ecology and sustainable development of mountain ecosystems; second, promoting integrated watershed development and alternative livelihood opportunities. Given the particular susceptibility of mountainous regions to a rapidly changing environment and to human pressures, any strategy to improve their management and protection over a decadal time frame must include the potential impacts of global change as a central element.

The international workshop held from March 30 - April 2 at the International Centre for Integrated Mountain Development (ICIMOD) at Kathmandu, Nepal, aimed to build on earlier and ongoing initiatives and distill the components required to establish a coherent, focussed international research effort within the IGBP based on the sharp environmental gradients found in mountainous regions.
BAHC and GCTE initiated the Kathmandu workshop and were responsible for its scientific programme. Both are interested in integrated altitudinal gradient and associated catchment hydrology studies primarily for their role in understanding the basic global change issues identified above. BAHC’s specific interests are to improve the understanding of the spatial distribution pattern of key hydrological characteristics such as precipitation, soil moisture, runoff formation and associated constituent transports, as a function of topography and related land surface features, in particular biospheric characteristics (Becker et al. 1994). GCTE has an interest in altitudinal gradient studies because a wide range of variation in ecosystem structure and functioning can be covered, and because altitudinal gradients are in many ways complementary to latitudinal gradient studies (Koch et al. 1995 a, b; Körner et al. 1991, Chapin et al. 1995).

In addition, BAHC and GCTE are keen to see this basic understanding applied to impact studies designed to support sustainable development strategies. BAHC and GCTE intend to provide the basic understanding of global change impacts on hydrology and terrestrial ecosystems that will underpin the impact studies undertaken by other groups, many of which will be working within the partner IGBP programme elements such as PAGES and LUCC (IGBP/IHDP), and through the START regional networks around the world.
Workshop Objectives

The objectives of the Kathmandu workshop were given as follows to:

- Define the key global change-related scientific questions in hydrology and ecology that can be addressed with sharp environmental gradients based on topography
- Develop a scientific “Mountain Workplan” for coordinated BAHC/GCTE research in mountain regions, with particular emphasis on:
  - assessment and modelling of the interactive influence of topography and land surface heterogeneity on the spatial pattern of soil moisture, evapotranspiration, runoff generation and erosion
  - collaborative ecological, micro-meteorological and hydrological process studies along altitudinal gradients coupled, where feasible, with integrated catchment hydrological studies
  - measurements, manipulative experiments, and modelling studies of ecosystem dynamics along altitudinal gradients
  - requirements for measurement techniques in harsh mountain environments.

For the development of the workplan, three main activities were identified, and each activity was subdivided into three research tasks. They are presented and discussed below.
The Proposed Mountain Workplan

Many ecological and hydrological studies in mountain regions to date concentrated on single sites or single, small catchments, respectively (Beniston 1994). Little is still known about the behaviour of ecological and hydrological processes along altitudinal gradients or about the downslope progression of upslope impacts. Therefore, it is an urgent research need to study hydrological and ecological processes and their interaction along altitudinal gradients, with a particular emphasis on the influence of land surface characteristics (Activity 1).

As described above, the susceptibility of mountain areas to Global Change makes it likely that they are the best, or at times the only areas, where the impacts of climate change on the hydrosphere and biosphere can be identified and studied. This, however, requires a scientifically sound, feasible methodology including observation, manipulative experimentation, and modelling (Activity 2).

Finally, mountain regions are eminently important for human communities living in the mountains as well as downstream. In many mountain areas land-use pressure as well as the risk of natural disasters is increasing (e.g., Hewitt 1992, 1997). Hence the issue of Global Change and Sustainable Development is of key importance (Activity 3).

Activity 1: **Study Hydrological and Ecological Processes and Their Interaction Along Altitudinal Gradients as a Function of Land Surface Characteristics**

Natural processes and socio-economic responses along altitudinal gradients in mountain areas change very rapidly over short distances. Along altitudinal gradients, ecosystems often show differential, highly non-linear responses to changes in environmental parameters. Hence the extrapolation of information gathered from site-oriented studies often is not appropriate. On the other hand, vegetation stabi-
lizes soils and has a profound influence on hydrology and, specifically, on downslope safety. Thus, comprehensive, gradient-oriented basic research is a fundamental requirement to advance a predictive understanding of hydrology and ecology in mountain regions.

Specifically, we are facing a three-fold challenge:

1. Monitoring and manipulative experiments are required to study in situ the ecological and hydrological processes along altitudinal gradients (Task 1.1).

2. In addition, considering the process understanding gained from Task 1.1, special emphasis should be put on linking the knowledge from ecology and hydrology, and in particular on its extrapolation to larger spatial scales, as a step towards integrated impact assessments (Task 1.2).

3. Mathematical models need to be developed to describe and test hypotheses about these processes under current climate as well as to predict the possible impacts of Global Change on these processes (Task 1.3).

**Task 1.1 Monitoring and Manipulative Experiments Along Altitudinal Gradients for Understanding Hydrological and Ecological Processes and Their Interactions**

Ecological experiments along altitudinal gradients, in particular manipulative ones, could provide invaluable data on the differential response of individual species and of vegetation cover to anthropogenically induced environmental changes and on how these biotic changes will in turn influence hydrological processes and surface energy, water and trace gas fluxes (see also Task 1.2). Examples of such experiments (e.g., Clausen et al. 1948, Mooney and Billings 1965, Clements et al. 1950, Rawat and Purohit 1991, Prock and Körner 1996) would be:

- Transplant experiments: moving species or communities down along altitudinal gradients to test their response to higher temperatures and a concomitant change of other factors, such as an increase of the partial pressure of atmospheric CO₂ and a decrease of UV-B radiation

- In-situ experiments: for example, increasing the temperature by use of International Tundra Experiment (ITEX) shelters. In such experiments there is no change in CO₂ and UV-B, but many other factors change together with temperature. It could be quite instructive to compare these experiments with the transplant studies outlined above. The comparison could demonstrate the relative importance of temperature as a controlling factor of vegetation structure. Similarly, UV-B screens could be used to filter out UV-B radiation while leaving all other factors unchanged. Another type of experiment would involve manipulations of snow duration to study the effects of growing season length on vegetation.

Within GCTE, there are considerable efforts going on aimed at quantifying the relationship between ecological complexity (biodiversity) and ecosystem functioning (Steffen et al. 1992). Altitudinal gradients have the potential to greatly increase our
knowledge about this relationship (Körner 1995) by providing answers to questions such as:

- How does complexity (diversity) both in terms of species and functional types change as altitude increases, and how is this related to vegetation functioning?
- Does the number of species which belong to a single functional type decrease as altitude increases? How does this affect function?
- What is the effect of adding or removing certain functional types at various elevations along mountain transects?

Finally, for a number of reasons the definition of Plant Functional Types (PFTs) has received increasing attention over the past years (e.g., Woodward and Cramer 1996), most notably because at larger spatial scales impact assessments based on single species are hardly feasible. While the definition of a set of PFTs is quite easy, testing its applicability in real-world situations continues to be a difficult task (e.g., Bugmann 1996a). In this respect, a comparison of altitudinal and latitudinal gradients could be useful for defining and testing classifications of plants into PFTs (e.g., nitrogen-fixers, species dominating transpiration, canopy dominants, etc. see Körner et al. 1991). The aim here would be to define a set of PFTs that is globally applicable based on data from the two types of gradients.

At each experimental site along altitudinal gradients the ecological and hydrological studies need to be complementary to each other. For example, ecological manipulations need to be accompanied by an extensive measurement programme of the affected hydrological parameters and variables to understand the interactions and facilitate the extrapolation of the results (see Task 1.2).

**Task 1.2  Assessment of the Spatial and Temporal Variation of Hydrological and Ecological Processes and Their Interaction in Mountain Regions as a Function of Climate and Land Surface Properties**

Traditionally, ecologists tend to focus on site-specific investigations neglecting any spatial aspects, most notably lateral fluxes of water and nutrients. On the other hand, in hydrological studies vegetation properties are often assumed to be uniform across the investigated area. When they are differentiated in space, they are often assumed to be static. Hence, to achieve a thorough understanding of global change impacts on hydrology and ecology at the landscape and larger scales, the knowledge from both disciplines must be coupled (cf. Cernuska 1989), e.g., through modelling.

In this respect, the following sub-tasks need to be solved:

- Determine how changes in environmental characteristics and land use along altitudinal gradients, in headwater catchments and at the regional scale affect and/or control hydrological processes (e.g., evapotranspiration, infiltration and runoff), biogeochemical fluxes, vegetation structure, biological productivity, and other characteristics such as erosion and slope stability
- Determine how biological productivity, vegetation structure and composition along altitudinal gradients and at the regional scale will be affected by changes in hydrogeochemical processes
• Develop models of how precipitation partitioning (snow/rain) under different warming scenarios will affect vegetation along altitudinal gradients and on regional scales

• Improve the ability of patch-scale vegetation models to predict current and future vegetation cover types and the resulting changes in hydrological characteristics, in particular energy and water fluxes, along altitudinal gradients and at the regional scale.

Hydrological investigations along altitudinal gradients combined with catchment studies in headwater basins, including tracer experiments, are of particular importance here (cf. Beven and Kirkby 1979, McDonnell 1990, Hermann 1993–1994, Anderson and Brooks 1996, Körner et al. 1989, Müller 1965, Baumgartner et al. 1983). They should help to identify the different flow paths of water and its constituents along mountain slopes, and to determine the related residence times of water that are crucial for biogeochemical processes.

The in-depth study of the linkages between hydrological and ecological patterns across broad altitudinal gradients will allow us to:

• Generate hypotheses regarding the interacting effects of temperature and other environmental variables on biotic and hydrological processes

• Identify optimum sites for more intensive studies and monitoring plots (cf. Task 2.3) and manipulative experiments (cf. Task 1.1).

The spatial extrapolation of measurements and experimental results will be based on the application of simulation models using geo-referenced data bases. Extrapolation in time, requiring retrospective or future predictions of vegetation distribution will utilize palaeoecological data (derived in collaboration with PAGES; cf. Wake and Mayewski 1995) and simulation models of vegetation structure and composition.

In this context, it will be necessary to develop scale-sensitive interfaces between patch-scale vegetation models and variously scaled models of land surface processes (see Box 2).

A special problem in mountain regions, i.e., in any study along altitudinal gradients and on larger scales, is the adequate assessment of the controlling meteorological characteristics, in particular the spatial and temporal pattern of precipitation in form of rainfall and/or snow (Franz 1980). Monitoring networks are generally not adequate to sample the heterogeneity of the mountainous environment for a number of reasons (harsh conditions, difficult access, sparse settlement, especially at higher elevations). The recommendations of WMO concerning the minimum density of meteorological and hydrological networks are, as a rule, not fulfilled world-wide. However, even where the network density is satisfactory it does not necessarily reflect the spatial patterns of meteorological and hydrological variables in an adequate way because of the improper location of stations (valley floors rather than higher elevations) and the mountain-specific large spatial variability, including altitudinal variability. These problems can be addressed by using the water balance check combined with modelling (Box 3).
There is an urgent need to develop strategies for network design and monitoring to adequately assess at different scales the spatial and temporal patterns of basic water balance components such as precipitation, evapotranspiration and runoff in mountainous regions. Besides increasing the spatial density of the networks, it is also imperative that the existing stations are operated as long as possible, but at least for some decades.

Taking into account these problems and needs, it is recommended in Chapter 13 of Agenda 21 that governments, with the support of the relevant international and regional organizations, should establish and maintain meteorological and hydrological monitoring networks that would encompass water distribution in various mountain regions of the world. These recommendations have not yet been put into practice. Therefore in connection with the suggested Proposed Mountain Workplan, special attention needs to be paid to this call of the Agenda 21.

Task 1.3 Modelling the Impacts of Climatic and Land Use Changes on Hydrological and Ecological Processes in Mountain Regions

Several lines of models need to be improved and developed further to be able to predict the possible impacts of Global Change on mountain regions:

- Advanced meso-scale high resolution atmospheric models need to be developed as operational tools for the routine assessment and prediction of spatial precipitation patterns in mountainous regions (cf. Box 3). The spatial resolution of the current generation of models comes close to fulfilling this requirement, but special efforts are needed to achieve wider practical application.

- Our ability to describe water, nutrient and sediment fluxes down altitudinal gradients and in associated watersheds in particular at larger scales needs to be improved by developing spatially distributed topography-based models (e.g., Beven 1991).

- Current models of vegetation structure and function typically were constructed for application at single sites, and they often can not be used to investigate the behaviour of ecosystems along environmental gradients (e.g., Bugmann 1996b). Improved models need to be developed which also allow one to assess the impacts of vegetation changes on hydrological processes (see also Task 1.2), taking particularly into account the timing and character (rain vs. snow) of precipitation. Furthermore, it would be desirable if these models could be based on the concept of Plant Functional Types (PFTs), which would render them more generally applicable (see Körner 1993 for a discussion). A key performance criterion for the vegetation models will be the prediction of critical hydrological variables (such as transpiration, infiltration and macropore flows, etc).

These three types of models need to be validated rigorously, again making use of data obtained from altitudinal gradient/catchment studies (cf. Task 1.1). For example, it will be important to evaluate whether data from altitudinal gradients can be used to test patch-scale models of ecosystem dynamics developed as an integral part of GCTE Task 2.1.3 (Steffen et al. 1992). Specifically, after site-specific calibration the models will need to be able to predict the observed change in ecosystem structure with, for example, a systematic change in temperature.
Biotic and hydrological processes interact on scales ranging from leaves and pedons ($10^{-1}$ m) through patches ($10^1$ to $10^2$ m) and watersheds ($10^3$ m) to regions ($>10^4$ m). Logistical constraints prevent an investigation of every possible interacting process. An iterative approach involving conceptual and/or numerical alteration between upscaling and downscaling (so-called “Strategic Cyclical Scaling”) has been shown to be an effective research strategy for investigating the interactions between fine-scaled ecological processes and larger-scaled hydro-climatic processes (Root and Schneider 1995).

In particular, strategic cyclical scaling allows us to:

- Identify fine-scaled processes that interact to produce emergent properties at larger spatial and/or temporal scales
- Identify the constraints imposed by large-scaled processes on interactions at finer scales.


Box 3

Checking the appropriateness of precipitation gauge networks in mountainous regions.

A. Water Balance Check

The water balance check is valid for catchments in which observation networks of precipitation and runoff do already exist. It is based on the fact that having a good estimate of runoff in a gauge terminating the sub-catchment and a number of rain gauges in this sub-catchment, one can estimate the value of actual evapotranspiration as the difference between spatial precipitation and runoff computed over a long time period. Repeating this procedure over a number of sub-catchments at different altitudes one can arrive at a relation between the actual areal evapotranspiration and altitude which has been found in many previous cases to show physically non-realistic behaviour (e.g., more runoff than precipitation, increase of actual evapotranspiration with altitude). The reasons for these inconsistencies are believed to be:

- Systematic errors of rain gauges, which need to be corrected
- Non-representative siting of rain gauges. For instance, most gauges are located in valleys, for convenience of installation, access and maintenance, and not on slopes, where they are needed.

It is suggested that the following procedure is applied in a number of mountain catchments world-wide, where observation networks are already existing:

1. Choose mountainous catchments with reliable runoff measurements at different elevations and a number of rain gauges.
2. Estimate areal precipitation values for these catchments at different elevations after having accounted for necessary systematic corrections of precipitation measurements.
3. Produce the plot of actual evapotranspiration as difference between long-term totals of precipitation and runoff (at least one year, or better, several years) for the different elevations and examine the physical sense and plausibility of the obtained relationship.
4. Eventually, if climatic data are available, evaluate evapotranspiration and counter-check the water balance over longer time periods.

This should be an iterative process, and if the steps 3 and/or 4 do not give physically realistic results, the siting of the gauges should be improved and/or additional gauges should be located on the slopes.

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**B. Modelling**

Modelling can be used at various scales to provide a preliminary analysis of where the possible gauge sites could be located. Land-atmosphere models can be useful also for completely ungauged basins. Running a land-atmosphere model with account of topography only gives an indication of where, in the catchment under study, precipitation could be large and where low. This would give some guidance as to where to place the gauges. Ideally, precipitation measurements obtained at these gauges can be fed into the land-atmosphere model providing indications for further improvement of the observation network alternatively, the water balance approach outlined above can be used to verify preliminary analyses.

Another modelling approach can also be used in studying spatial-temporal precipitation fields for evaluation of observing networks. These approaches include multivariate statistical models, geostatistical and physico-statistical models. Finally, studies of snow line positions, snow cover depths and multi-annual firn profiles could be used as diagnostic tools to estimate precipitation distributions in areas of complex topography.
Activity 2: Develop Measurement Protocols and Models to Use Ecological and Hydrological Characteristics of Mountain Regions as Indicators of Global Change

Three requirements have been identified for setting up a monitoring programme within the framework of this activity aimed at detecting the hydrological and ecological impacts of Global Change in mountain regions:

1. To identify ecological and hydrological characteristics which can most likely serve as reliable indicators of Global Change along altitudinal gradients (e.g., ecotones) (Task 2.1).

2. Based on the insights gained under Activity 1, a methodology needs to be developed further that allows altitude-related hydrological and ecological characteristics to be used as indicators of Global Change (Task 2.2).

3. Based on the results of Tasks 2.1 and 2.2 it is necessary to set up a coordinated monitoring programme across different altitudinal gradients and larger scales in mountainous regions (Task 2.3).

Task 2.1 Identification of Suitable Hydrological and Ecological Indicators of Global Change Impacts Along Altitudinal Gradients

To use the potential of mountain regions to study Global Change phenomena and their impacts, it is first of all necessary to identify those indicators that are most likely to show the earliest signals of Global Change impacts. The objective is to arrive at a relatively low number of hydrological and ecological indicators that can be monitored across many or all altitudinal gradients and high elevation studies.

Although the final list of suitable indicators is likely to be modified by the research to be conducted under this Workplan, a number of candidate indicators can be compiled at the present time:

- **Treeline and snowline**: changes of these boundaries may be detectable worldwide using high resolution remote sensing data (see below and Slatyer and Noble 1992).

- **Species occurrence and abundance at high elevations** to monitor potential species losses (cf. Grabherr et al. 1994).

- **Phenology**: Monitoring of the phenology of a limited number of indicator species which grow naturally or were planted at various heights along altitudinal gradients and may be quite sensitive indicators of temperature impacts, especially in the context of changing seasonality, including changes in the depth and duration of snow cover.
High alpine/nival aquatic ecosystems: These systems (typically small lakes) are located far from direct human influences and are therefore good indicators to assess natural background loads and to monitor indirect anthropogenic additions via the atmospheric part of the hydrological cycle. These systems provide opportunities to study changes in the hydrological cycle in mountains, to quantitatively assess and model eco-hydrologically active determinants, and to measure the biotic and abiotic scavenging abilities for immissions from the atmosphere. This allows determination of the ecological responses to global environmental changes at a sensitive organismic level. In this context, the suitability of high-altitude stream ecosystems as indicators of Global Change also needs to be addressed (e.g., Ormerod et al. 1994).

Comparing the shifts of physical (cryosperic) and ecotonal boundaries may be a tool to identify impacts of climate change on hydrology and ecosystems along mountain gradients. Such gradients encompass a wide variety of ecotones (e.g., lower [dry] treeline, upper [cold] treeline, alpine/nival ecotone, upper limit of vascular plant life) and cryospheric boundaries (lower limit of permafrost, rock-ice, ice-firm, firn-snow etc.), which are of different complexity. In combination with a latitudinal comparison of different mountain systems, this would increase our understanding of the impacts of climatic change.

However, physical and ecotonal boundaries are not necessarily sensitive to Global Change. For example, some ecotones are known to respond with very long lag times to environmental changes (Davis 1989), and some boundaries may not be sensitive to climatic parameters at all (e.g., Hättenschwiler and Körner 1995). Many ecotones exist as the result of disturbance, rather than climate, and in many cases these ecotones are causing climatic gradients (e.g., wind, evapotranspiration) rather than vice-versa. The selection of appropriate boundaries to be used as indicators thus will be crucial for this task.

Task 2.2 Development of a Methodology for the Coordinated Use of Altitude-Related Indicators to Identify Global Change and its Impacts

The working hypothesis for this task is that transition zones (i.e., ecotones and cryospheric boundaries) are likely to be most sensitive to Global Change. In addition, for a number of reasons outlined under Task 2.1, it was concluded that small, high alpine/nival aquatic ecosystems are likely to be very sensitive indicators of Global Change, at least for some of its facets. Consequently, the following issues need to be addressed:

- Provide an overview on the current knowledge on the past and possible future shifts of ecotonal and cryospheric boundaries (or derived indices) along altitudinal gradients. A good starting point in this respect is the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Watson et al. 1996, more specifically: Beniston et al. 1996, Kirschbaum et al. 1996)

- Develop the theoretical basis and models for understanding shifts of different altitudinal ecotones, including their temporal behaviour (time lag) in response to Global Change. In this respect, field manipulative experimentation (see also...
Task 1.1) on how vegetation cover types along altitudinal gradients may change as a consequence of anthropogenically induced environmental change (land use, climate, etc.) will play an important role

- Develop the theoretical basis and models about changes of the cryospheric system and, specifically, cryospheric boundaries to solve unresolved research issues (e.g., what is the time lag and the scale of the response to climate change of cryospheric indices) based on altitudinal gradient studies and the interpretation of remote sensing images and topographical tapes

- Provide the theoretical basis and technologies for using high mountain ecosystems as indicators of environmental variability and global change. Special attention should be paid to: i) natural background loads in precipitation and atmospheric deposition; ii) human-induced additions to the atmospheric part of the hydrological and biogeochemical cycles; iii) biotic and abiotic scavenging abilities for immissions from the atmosphere; and iv) the role of seasonality, freeze-thaw cycles, episodic events, lithology, soil, and vegetation

- Relate these indicators to each other so as to identify whether several indicators are linked and thus can be used in a coordinated way to monitor Global Change and its impacts.

Task 2.3 Establishment of a Global Monitoring Programme

The general objective of this task is to develop a protocol for monitoring programmes, i.e., studies combining field measurements and remote sensing for those cryospheric and ecotonal boundaries, systems and characteristics that have been proven to be the most sensitive indicators of Global Change (Task 2.1).

A number of general requirements should be met for a successful monitoring programme to be established across a number of altitudinal gradients in different parts of the world:

- Monitoring sites and gradients have to be well-defined with respect to structure and seasonal dynamics

- To minimize methodologically based discrepancies in the results, working hypotheses and working tools need to be harmonized among the different teams

- The quality of the data has to be scrutinized regularly

- Agreement needs to be reached on the taxonomy of indicator taxa, on the statistical methods employed, on the standardization of the database, and on the instrumentation and parameters selected for recording of climatological and hydrological parameters

- Analyses which require special expert knowledge and instrumentation should be performed only at a few well selected sites/gradients by experienced research groups.
For high alpine and nival aquatic ecosystems, which act as sinks for contaminants (nutrients and pollutants) transported especially through the atmosphere, it will be especially important to:

- Study the transfer of anthropogenic emission components to mountain ecosystems
- Measure nutrient solutes, organic and inorganic contaminants, acidity, and particulate deposition
- Quantify the impacts on the ecosystems of these additional loads
- Define the temporal and spatial response to these depositions of ecosystems
- Assess the scavenging of the immission by abiotic and biotic interception.

For these ecosystems, it will also be indispensable to assess the climate-induced spatial and temporal variability of the suspended load as a function of water discharge, with special reference to nutrient status.

**Activity 3: Develop Concepts for Sustainable Development Based on Relations Between Socio-Economic Conditions and Ecological/Hydrological Characteristics at Different Altitudes in Mountain Regions**

Within the context of global change, the major driving forces to be considered in the anthropogenic alteration of mountain landscapes are population changes and economic activities. These driving forces vary considerably between the world’s mountain regions, but also within individual mountain regions on sub-regional scales. Consequently, it is necessary to define these regions not only by their climatic, ecological and other biophysical characteristics, but also in terms of their socio-economic characteristics. For this purpose a classification based on that of Grötzbach and Stadel (1997) is particularly useful (Box 4).

The general task of Activity 3 is to perform spatially and temporally coordinated integrated research at the watershed scale on climate, hydrology, soils, land use, land cover, ecosystem functioning, resource utilization, population dynamics, and economic and policy variables. The aims are: i) to understand, quantify and model altitude-specific relationships between the measured variables and factors; and ii) to understand and model the relations and dependencies between upstream (mountains) and downstream (lower mountain parts and lowlands) conditions and changes in these conditions (e.g., hydrological conditions in terms of water resources availability, flood risk, sediment loads etc. in relation to climate and land use and their changes). Thus, studies are needed not only along altitudinal gradients and
within the mountain regions themselves but also along the river courses from headwater basins to the lowlands. Results of these studies should serve as a basis for the development of land and water use/management practices which guarantee sustainable development and avoid the degradation of land and natural resources, as well as hazards (natural disasters, etc.).

From the point of view of sustainable development, criteria for selecting transects, in addition to those mentioned above, are that they should include sub-regions/watersheds where the following developments take place:

- Changes in land use which are likely to result in major changes in hydrology (e.g., change from subsistence to market agriculture, conversion of forest to agriculture or grazing land, or vice versa)
- Rapid changes in population (e.g., out-migration, short-term [tourists] or long-term immigration, rapid population growth)
- Contrasting climatic types within each of the three socio-economic types
- Series of small watersheds at different altitudes within a large river basin, chosen for contrast and comparability of both land uses and population dynamics.

Within the frame of sustainable development, a wide array of themes could be selected for in-depth studies. In the present context, three major themes were identified, but this list is in no way complete:

1. Quantifying the altitude-specific relationships between socio-economic characteristics, in particular land use, and hydrological and ecological processes. Identifying these relationships and analysing how they may change in the future will be of prime importance for integrated impact assessments and for developing strategies for sustainable development (Task 3.1).

2. In many mountain regions of the world, especially those where population growth is high, soil erosion is a major problem, partly caused by changes in land use and land cover. Concepts need to be developed to ensure environmental protection and sustainable agriculture and forestry for these areas (Task 3.2).

3. It has long been known that the impacts of a change in the frequency of extreme events may be much more important than some change of an average climatic parameter (e.g., Katz and Brown 1992). This is especially true for mountain regions, where the impacts of extreme events are often amplified through slope effects, and where mountain people need to maintain their livelihoods. The investigation of the modificatory effects of ecosystem structure and land-use practices on the impacts of extreme events will further the development of protection measures and mitigation strategies for this type of natural disaster (Task 3.3).
Task 3.1 Quantification of the Altitude-Specific Relationships Between Socio-Economic Characteristics, in Particular Land Use, and Hydrological and Ecological Processes

At the landscape scale, quantitative relationships between land use/cover and hydrological and ecological processes are relatively poorly known, whereas at the patch and hillslope scales a considerable body of information exists. Furthermore, these relationships are likely to vary considerably as a function of altitude (among others through downslope propagation of processes).

To quantify these altitude-specific relationships, it will be necessary to identify critical variables as well as critical areas along altitudinal gradients within and between watersheds. These variables and areas then are also prime candidates for a long-term monitoring programme as outlined under Activity 2.

We, the workshop participants, advocate the implementation of parallel altitudinal gradients in a given mountain region that differ with respect to land use/land cover. The comparison of altitudinal gradients with and without human-modified vegetation (e.g., grazed and logged, compared to pristine and/or abandoned areas) will aid in understanding the land-use effects at the landscape scale (cf. GCTE Activity 2.2, Steffen et al. 1992 [IGBP Report 21]).

Task 3.2 Develop Altitude-Specific Management Practices for Mountain Ecosystems which Ensure Sustainable Development and Environmental Protection in the Mountain Regions as well as for Downstream Communities

Mountain environments, including their climates, are highly variable in space and time. Local people have much knowledge about this local-scale variability and its potential and constraints for economic activities, such as agriculture and forestry. This is an essential complement to scientific data, which are often insufficient to characterize mountain climates.

Therefore, research should be done on traditional/indigenous knowledge of strategies for dealing with environmental change and natural disasters. Approaches such as “Participatory Rural Appraisal” (Mukherjee 1993) should be used to determine local people’s perceptions of environmental change, and their related needs and priorities. The results of these efforts should be tightly linked to other research activities aimed at determining best practices for ecosystem management.

Global climate change is likely to lead to an intensified hydrological cycle, though regional and sub-regional decreases in precipitation and available moisture are also possible (Barry 1992, Kattenberg et al. 1996). The impacts of an intensification of the hydrological cycle, most notably in connection with the possibility of an increasing occurrence of extreme events (see task 3.3) are also important to the millions of people living downstream of mountain river basins. It should be recognized that many events (e.g., floods, droughts) in the lower parts of river basins are attributed to land use practises and/or deforestation in the upper parts of these basins. However, these cause-effect relationships are not proven sufficiently and require further research.

Research should be integrated, involving hydrologists, ecologists, meteorologists and social scientists from various disciplines. All spatial data should be geo-referenced and compiled in geographical information systems (GIS) to permit correlation and analysis and the development and testing of models. An integrated watershed
approach, coupled with meteorological, ecological and other studies as mentioned earlier, is considered most appropriate for watersheds (river basins) of different size and character, and crossing different ranges in altitude. It allows the establishment of water and biogeochemical budgets for larger areas (i.e., the basin areas) and to study their changes under changing land use and climate conditions.

**Task 3.3  Assessment of Interactions Between Ecosystem Structure, Land Use Practices and Extreme Events (Floods, Droughts, Erosion, Landslides etc.,) as a Basis for the Development of Protection Measures and Mitigation Strategies**

Altitudinal shifts in land use patterns affect soil stability and biodiversity and thereby alter hydrological processes. Such altitudinal shifts may partly be driven by changes in climate; for instance the migration of people and, hence, the associated changes in land use along altitudinal gradients. Consequences of such shifts are changes in crop types and cropping patterns, recreational patterns, and forestry practices. On the other hand, many shifts of land use patterns are driven by increasing population pressure, leading to overexploitation of the land and subsequent erosion, or by a combination of economic forces and government policies, which may lead to diverse effects, from increasingly intensive use of mountain regions to their widespread abandonment.

Soil erosion and the loss of agricultural land are critical issues for most mountain regions in the developing world.

Changes of climate, population dynamics, economic forces, and government policies are interlinked factors. Nearly every change in land use has a measurable and significant effect on hydrological and ecological processes. It should also be recognized that economic forces are often short-term, and that the resulting land uses may not be sustainable, especially under a changing climate.

It is likely that global climate change will lead to increased climatic variability, thus affecting the frequency and magnitude of extreme events. This would lead to an increased risk of natural disasters (e.g., floods, severe soil erosion, landslides, avalanches). All of these changes would be of great significance to mountain people, who need to maintain their livelihoods.

In this context, the following issues need to be addressed:

- Estimate how the frequency and amount of extreme events depends on the macro-, meso- and micro-level changes of climate and land use
- Investigate the physical impacts of extreme events on natural resources and the people themselves, and evaluate the responses at different levels: individual, community, organization, etc.
- Develop mitigation strategies in relation to extreme events.

As a first step towards addressing these issues, it will be necessary to create scenarios for the occurrence of extreme events and to assess their impacts at various levels. Then it will become possible to develop appropriate land use pattern and management practices which protect the environment and ensure the maximum possible reduction of losses and mitigation of damages.
Box 4

Socio-economic classification of mountain regions. After Grötzbach and Stadel (1997).

1. Sparse to high population density, high population growth, economy dominated by subsistence agriculture and/or grazing, forests used for domestic and commercial purposes, tourism in limited areas (e.g., Himalayas, Andes, mountains of Central America, Africa, Southeast Asia).

2. Relatively densely populated, market-oriented agriculture and forestry often heavily subsidized by governments, widespread tourism, depopulation in areas where economic activities or subsidies no longer provide adequate livelihoods (mountains of Europe and Japan).

3. Sparsely populated, market-oriented grazing and forestry, tourism in scattered locations (mountains of North America, New Zealand, Australia).
Conclusions and Recommendations

Considering the recent developments of the state of natural and socio-economic systems in mountain regions, it can be concluded that these systems are at risk and need special attention, in particular with respect to the possible impacts of global change. Intensified, collaborative and coordinated research is required, which can be fostered best through an international research programme.

This is in full agreement with Agenda 21, Chapter 13, “The Mountain Agenda” of the UNCED, and it was clearly confirmed by both the workshop in Kathmandu and the IGBP Congress in Bad Münstereifel, Germany, in April 1996. The draft plan of activities and tasks as presented in this documentation (see Appendix I) may serve as a basis for the development of the required international research initiative in the framework of the IGBP.

The most effective research strategy is one in which regional context shapes and prioritizes the implementation of research projects. In particular, scientists from different regions in which altitudinal gradients are located should participate as equal partners in the design and implementation of research plans. This partnership model is especially critical in the context of the developing world where regional scientific expertise has often not sufficiently been integrated into international research programmes. To overcome this shortcoming, the partnership model as suggested in IGBP Report No. 34 should be applied (BAHC-IGAC-GCTE Science Task Team 1995, p. 18).

All interested institutions and individuals are invited to comment on the proposed structure and contents of the “Mountain Workplan” as summarized in Appendix I of this document, and to submit proposals for its further improvement and completion. The Editors of this document as well as the IPOs of BAHC and GCTE would be happy to receive such suggestions.
References


### List of Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>BAHC</td>
<td>Biospheric Aspects of the Hydrological Cycle (IGBP)</td>
</tr>
<tr>
<td>BMBF</td>
<td>German Federal Ministery for Education, Research and Technology (translation)</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organizations</td>
</tr>
<tr>
<td>EU</td>
<td>European Union (formerly European Community)</td>
</tr>
<tr>
<td>GCTE</td>
<td>Global Change and Terrestrial Ecosystems (IGBP)</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information System</td>
</tr>
<tr>
<td>ICIMOD</td>
<td>International Centre for Integrated Mountain Development</td>
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<tr>
<td>ICSU</td>
<td>International Council of Scientific Unions</td>
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<tr>
<td>IGBP</td>
<td>International Geosphere-Biosphere Programme (ICSU)</td>
</tr>
<tr>
<td>IHP</td>
<td>International Hydrological Programme (UNESCO)</td>
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<tr>
<td>IHDP</td>
<td>International Human Dimensions Programme on Global Environmental Change</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IPO</td>
<td>International Project Office (formally Core Project Office (CPO))</td>
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<tr>
<td>ITEX</td>
<td>International Tundra Experiment</td>
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<tr>
<td>LTER</td>
<td>Long-Term Ecological Research</td>
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<tr>
<td>LUCC</td>
<td>Land-Use/Cover Change (IGBP/IHDP)</td>
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<td>MAB</td>
<td>Man and the Biosphere Programme (UNESCO)</td>
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<tr>
<td>NSF</td>
<td>National Science Foundation (USA)</td>
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<td>PAGES</td>
<td>Past Global Changes (IGBP)</td>
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<tr>
<td>Acronym</td>
<td>Full Term</td>
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<td>PFT</td>
<td>Plant Functional Type</td>
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<tr>
<td>SANW</td>
<td>Swiss Academy of Natural Sciences</td>
</tr>
<tr>
<td>SASCOM</td>
<td>South Asian START Committee</td>
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<tr>
<td>SC-IGBP</td>
<td>Scientific Committee (IGBP)</td>
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<tr>
<td>SSC</td>
<td>Scientific Steering Committee</td>
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<tr>
<td>START</td>
<td>Global Change System for Analysis, Research and Training (IGBP/WCRP/IHDP)</td>
</tr>
<tr>
<td>UNCED</td>
<td>United Nations Council for Environment and Development</td>
</tr>
<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organization</td>
</tr>
<tr>
<td>WCRP</td>
<td>World Climate Research Programme (ICSU/WMO/IOC)</td>
</tr>
<tr>
<td>WMO</td>
<td>World Meteorological Organization (UN)</td>
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## Appendix I

### Summary of Activities and Tasks

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<th>Activity 1</th>
<th>Study hydrological and ecological processes and their interaction along altitudinal gradients as a function of land surface characteristics</th>
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<tbody>
<tr>
<td><strong>Task 1.1</strong></td>
<td>Monitoring and manipulative experiments along altitudinal gradients for understanding hydrological and ecological processes and their interactions</td>
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<td><strong>Task 1.2</strong></td>
<td>Linking understanding of hydrological and ecological processes in mountain regions, emphasizing their spatial and temporal variation and interrelations</td>
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<td><strong>Task 1.3</strong></td>
<td>Predictive modelling of hydrological and ecological processes along altitudinal gradients</td>
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<th>Activity 2</th>
<th>Develop measurement protocols and models to use ecological and hydrological characteristics of mountain regions as indicators of Global Change</th>
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<tr>
<td><strong>Task 2.1</strong></td>
<td>Identification of suitable hydrological and ecological indicators of Global Change impacts along altitudinal gradients</td>
</tr>
<tr>
<td><strong>Task 2.2</strong></td>
<td>Development of methodologies for using altitude-related indicators to identify Global Change and its impacts</td>
</tr>
<tr>
<td><strong>Task 2.3</strong></td>
<td>Establishment of monitoring programme</td>
</tr>
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</table>
Activity 3  Develop concepts for sustainable development based on relations between socio-economic conditions and ecological/hydrological characteristics at different altitudes in mountain regions

Task 3.1  Quantification of the altitude-specific relationships between socio-economic characteristics, in particular land use, and hydrological and ecological processes

Task 3.2  Develop altitude-specific management practices for mountain ecosystems which ensure sustainable development and environmental protection in the mountain regions as well as for downstream communities

Task 3.3  Assessment of interactions between ecosystem structure, land use practices and extreme events (floods, droughts, erosion, landslides etc.) as a basis for the development of protection measures and mitigation strategies
Appendix II

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Appendix III

Workshop Presentations

Y.P. Abrol  CO$_2$ and temperature in relation to wheat
S.P. Adhikary  Assessment of land use change and the need for transect studies
R. Avissar  Use of coupled mesoscale atmospheric and land-surface process modelling to derive precipitation along altitudinal gradients
J. Bahadur  Distribution of winter and summer precipitation over the Himalayan region
A. Becker  Multiscale modelling and the nested drainage basin approach
M. Blumthaler  Altitudinal variation of UV-B radiation
W. Bowman  Experimental design of ecological and hydrological studies in mountain research catchments
H. Bugmann  Performance of patch models of ecosystem dynamics at single sites, along altitudinal gradients, and in mountain landscapes
S.R. Chalise  Special hydrological problems and tasks in the Himalayan region
D. Collins  Recent research activities in the nival zone of the Himalayas
A. Gillison  Global eco-regional gradient baseline studies in the humid tropics: the CIFOR Forest Ecosystem Management Project
G. Grabherr  Long-term shifts of alpine ecotones, with special reference to the alpine/nival ecotone
L. Graumlich  Scale issues and land-use change: the challenge of integrating biophysical and social science data
K. Hanselmann  High mountain aquatic ecosystems as indicators of environmental variability and change
A. Herrmann  Experimental studies coupled with modelling to identify water pathways and residence times
J. Holten  Altitudinal distribution patterns of vascular plants and their relations to local/regional climate regimes
N.R. Khemal  Highland-lowland linkages in water and sediment discharge
C. Körner I.  Mountain ecosystems in a changing world II. The influence of elevated CO₂ on high mountain ecosystems
A. Krenke  Use of snow line data to assess snow accumulation, precipitation and runoff in high mountain systems
H. Lang  Climate change impacts on the hydrology of the Thur/Rhine river basin
J. McConnell  Requirements for long-term ecological studies in mountainous regions
J. McDonnell  Investigation and modelling of runoff sources and streamflow generation
M. Price  Changes in mountain hydrology and ecosystems: the human dimension
A.N. Purohit  Form and functional changes in mountain plants with changing climatic conditions
S.C. Rai  Landscape assessment of hydrology and nutrient flux in an agrarian watershed of the Sikkim Himalaya
R.E. Schulze  Crop and biomass modelling in mountainous terrain: considerations, problems and challenges
B. Sevruk  Design and use of ground-based networks, modelling and remote sensing to assess the areal precipitation pattern in mountainous regions
R.B. Singh  Land use change pressures, hazards and hydrological and ecological responses to global change
V. Subramanian  Proposed BAHC related activities in India.
Appendix IV

Minutes of a Meeting at the IGBP Congress, April 1996

Minutes of the Meeting on Global Change Impacts on Mountain Hydrology and Ecology

IGBP Congress, Bad Münstereifel/Germany, Day 4 (21 April 1996)

Participants:  24 (BAHC 6, GAIM 1, GCTE 5, LUCC 1, PAGES 6, START 3, IGBP- Secretariat 2).

The meeting was informed by A. Becker on the results of the joint BAHC-GCTE-START/SASCOM Workshop from 30 March to 2 April 1996 in Kathmandu/Nepal. The basis for this information was the draft workshop report which had been distributed before the meeting to the participants.

In the discussion the Kathmandu workshop was evaluated as a valuable initiative, being very timely with regard to Agenda 21, Chapter 13 (The “Mountain Agenda”). The intention to provide from the IGBP side the scientific basis for addressing the problems as outlined in the Mountain Agenda was strongly supported. Accordingly the proposed intercore project cooperation on “Global Change Impacts on Mountain Hydrology and Ecology” was generally welcomed. Representatives of PAGES and LUCC at the meeting expressed the interest of these core projects in participating in the cooperation and in the further development of the research programme for an intercore project cooperating between BAHC, GCTE, LUCC and PAGES.
The meeting appreciated the draft workshop report as distributed and considered the draft research programme proposal presented in this report as a basis for the development of a more focused proposal to be prepared jointly by the four participating core projects. A number of comments were given in this regard and proposals made, which are summarized here as follows:

1. The global relevance of “Global Change Research” in mountain regions needs to be pointed out more strongly. An essential argument in this context should be the importance of mountain regions to sustainable development. According to an ongoing investigation by relevant UN bodies, mountain regions provide water for various uses (multipurpose) to about 50% (at times up to 80%) of the world’s population. This “supply function” of mountains (identifying them as “water towers”) concerns communities not only in mountain regions themselves but also in water-limited downstream lowlands. Moreover, the role of mountain regions as environmental resources and recreation areas for tourism needs to be taken into account.

2. The programme should clearly focus on mountain-specific research which can best or only be carried out in mountain environments and which will provide results which are uniquely available from such environments. Duplication of activities already included in the research plans of the participating core projects is to be avoided.

3. To provide a common understanding of the term “mountain regions” in the context of the proposed research programme, the following definition was proposed:

Mountain regions are characterized by:

i. Substantial gradients in environmental characteristics (ecological, hydrological, etc.) due to rapid and sharp altitudinal gradients

ii. Mountain-specific dynamics of hydrological processes with important positive and negative consequences (high water yield due to high amounts of precipitation on the one hand, disastrous floods with soil losses by erosion, landslides etc., resulting in high sediment loads in rivers and sedimentation, on the other).

Alpine mountain areas with glaciers and long-lasting snow cover in the top ranges and with well developed vegetation cover and human settlement on lower slopes and in river valleys most typically represent “mountain regions”, but middle mountain ranges should not be excluded if they fulfil the above criteria i) and ii).

4. Two main research themes (foci) clearly emerged from the discussion:

i. Investigation of physical and biological ecotones and of selected high mountain ecosystems as sensitive indicators (critical monitors) of global change

ii. Integrated eco-hydrological investigations in mountain river basins to ensure sustainable development under the influence of global change.
Additional explanation is given as follows:

ad i. Ecotones of special interest are cryospheric lines (glaciers, snow), tree or timber line, upper boundaries of the occurrence of selected vegetation species etc. Small aquatic ecosystems in high mountains are particularly sensitive to changes. Below the timber line tree rings provide additional results with high resolution for a certain time period.

ad ii. Mountain regions are crucial source areas for water supply ("water towers"), ensuring sustainable development not only in the mountain regions but also in downstream water-limited lowlands. Moreover they represent valuable environmental resources, and thus recreation areas for tourism. Integrated river basin-related ecological, hydrological and land use investigations and modelling for the given and for changing conditions are needed to improve land and water management in a such way that stable water supply and sustainable development are ensured in a region.

Equally the potential of mountain environments to produce natural disasters as mentioned in (3ii) above needs to be taken into account (floods, erosion and sedimentation, landslides, etc.). In particular, an important aim is to determine land use and land cover patterns and management strategies which help to avoid or mitigate damaging impacts of disastrous events.

5. More specific proposals were made and recommendations given as follows:

i. BAHC and GCTE will contribute substantially to both themes 4i and 4ii, with GCTE contributing more strongly to theme 4i, and BAHC to theme 4ii. LUCC will be strongly involved in theme 4ii, PAGES more in theme 4i.

ii. The BAHC and GCTE contributions will be specified on the basis of the Kathmandu Workshop Report. Those activities and tasks will be selected from the list of suggested activities and tasks included in this report which are relevant for the two focused themes. They will be regrouped and perhaps reformulated as required or appropriate.

iii. PAGES offers contributions as follows:

- Providing and analysing hydrological palaeodata for mountain regions, in particular on glaciers, runoff and sediments, from activities planned within the PAGES project “Palaeo-aspects of fluvial systems”.

- An extremely important subtask here will be “Ice core drilling in mountain glaciers, especially in low latitudes” (tropical zones: New Guinea, East Africa, Andes), where glaciers are disappearing rapidly.

- Investigation of changes in upper tree or timberline and of tree rings as sensitive indicators of climate and environmental change, in particular within Pole-Equator-Pole (PEP) projects, e.g., PEP I (North-South America).
iv. LUCC will concentrate on the mountain-specific aspects of land use and land cover change.

v. It was suggested to start with the following activities with contributions from all contributing core projects:

- A synthesis of existing results on global change impacts in mountain regions
- An inventory of currently operative research in mountain environments to support better coordination and interpretation
- Planning of a global network of research sites (existing and new sites) and of research river basins with sharp altitudinal gradients best suited for integrated studies and for testing and developing patch and catchment scale models. Data availability is an aspect of primary concern here.

Finally, the suggestion was made to establish a task group with about 6 to 8 members from the four participating core projects (BAHC, GCTE, LUCC, PAGES). The following proposal for preliminary group membership was made and agreed in the meeting: BAHC - A. Becker and A. Krenke; GCTE - W. Steffen and I. Woodward; LUCC - L. Fresco; PAGES - B. Messerli. This group agreed to contribute to the preparation of these minutes and to act as a link to the SSCs of the core projects involved until the task group has been formally established.

A. Becker
Convener of the meeting
Appendix V

Summary of the Interests of PAGES Regarding the Proposed Mountain Workplan

Mountains have the most sensitive ecosystems to climate and environmental change: They are early warning systems for mankind!

In this context PAGES is very much interested in participating in the frame of its existing projects in the following ways, taking into account especially the global aspects:

**Hydrological Palaeodata (Glaciers, Run-Off, Sediments, etc.)**
Knowing that ca. 80 % of the global freshwater flow is coming from mountain areas, we should know more about changes of these resources.

This topic is in connection with the recently established PAGES-project "Human impact on fluvial systems", which will be changed to "Palaeo-aspects of fluvial systems".

**Ice Core Drilling in Mountain Glaciers, Especially in Low Latitudes**
Glaciers in tropical zones (New Guinea, East Africa, Andes) are disappearing very rapidly. In the near future we shall lose these archives for the reconstruction of climate and environmental changes in the tropics. This project is also very important for palaeohydrology.

This topic is in connection with the existing PAGES activities about high mountain climate research (workshop 1996 in Switzerland) and about ongoing ice-core drilling in the Andes, Tibet, etc.
Changes of the Upper Trees or Timberline

Tree- or timberline is very indicative for climate and environmental changes and tree rings give us a very high resolution for a certain time period.

This topic is in connection with the PEP (Pole-Equator-Pole) projects, especially in PEP I (North-South America) a long distance analysis of this sensitive indicator is planned.

Bruno Messerli
PAGES SSC
List of IGBP Publications

IGBP Report Series. List with Short Summary

IGBP Reports are available free of charge from:
IGBP Secretariat, Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden.

Report Nos. 1-11 and reports marked * are no longer available.

No. 12
The IGBP science plan is composed of research projects aimed at answering a number of key questions related to global change, through the establishment of Core Projects on the distinct sub-components of the Earth system, and related activities on data systems and research centres. An implementation strategy provides for its fulfilment.

No. 13
The Sigtuna workshop contributed to the development of a scientific action plan on terrestrial ecosystem gas exchange, complementing the International Global Atmospheric Chemistry Project (an IGBP Core Project) in areas of natural variability, boreal regions, global integration and modelling of fluxes, and trace gas fluxes in mid-latitude ecosystems.
No. 14
The focus of IGBP Coordinating Panel 2 on Marine Biosphere-Atmosphere Interactions is the elucidation and prediction of the feedback loops between climate and ocean biogeochemistry under conditions of significant anthropogenic changes to the trace gas composition of the atmosphere. The workshop concentrated on global change and the coastal oceans.

No. 15
START is a plan for the development of an international network of regional research centres and sites to gather data and study global change problems in their regional contexts. These regions are identified. Issues to be addressed are:何changes in land use and industrial practices alter the water cycles, atmospheric chemistry and ecosystems dynamics; how regional changes affect global biogeochemical cycles and climate; and how global change leads to further regional change in the biospheric life support system.

No. 16
The workshop discussed, in a South American context, past global changes, the effects of climate change on terrestrial ecosystems, the role of ocean processes in global change, land transformation and global change processes, the importance of the Andes for general circulation models, and regional research centres. Recommendations promote the role of South American science in global change research.

No. 17
The workshop addressed plant-water interrelationships at landscape to continental scales: the spatial pattern at landscape level of the dynamics of water flows and waterborne fluxes of dissolved and suspended mater; plant/vegetation characteristics and properties affecting return flow to the atmosphere; methodological issues of large-scale modelling; research in humid tropical, semi-arid and temperate zones.

No. 18:1
Recommendations of the Workshop address issues of prime concern to Asian countries, with reports and recommendations from Working Groups on IGBP Core Projects and key activities.
No. 18:2
The Proceedings include 19 papers on Earth system research and global environmental change in Asia, and national reports on global change programmes.

No. 19*
The Past Global Changes (PAGES) project will secure better understanding of the natural and human-induced variations of the Earth system in the past, through studies of both natural and written records. Focus is on changes within two temporal streams: global changes for the period 2000 BP, and changes through a full glacial cycle. Implementation plans address: solar and orbital forcing and response, Earth system processes, rapid and abrupt global changes, multi-proxy mapping, palaeoclimatic and palaeoenvironmental modelling, advances in technology, management of palaeodata, and improved chronologies for palaeoenvironmental research.

No. 20*
This report outlines a proposal to produce a global data set at a spatial resolution of 1 km derived from the Advanced Very High Resolution Radiometer primarily for land applications. It defines the characteristics of the data set to meet a number of requirements of IGBP’s science plan and outlines how it could be created. It presents the scientific requirements for a 1 km data set, the types and uses of AVHRR data, characteristics of a global 1 km data set, procedures, availability of current AVHRR 1 km data, and the management needs.

No. 21*
The objectives of GCTE are: to predict the effects of changes in climate, atmospheric composition, and land use on terrestrial ecosystems, including agricultural and production forest systems, and to determine how these effects lead to feedbacks to the atmosphere and the physical climate system. The research plan is divided into four foci: ecosystem physiology, change in ecosystem structure, global change impact on agriculture and forestry, and global change and ecological complexity. Research strategies are presented.
No. 22
The report presents general recommendations on global change research in the region, thematic studies relating to IGBP Core Project science programmes, global change research in studies of eight countries in the area, and conclusions from working groups on the participation of the region in research under the five established IGBP Core Projects and the related HDGEC programme.

No. 23
The Report describes how the aims of JGOFS are being, and will be, achieved through global synthesis, large scale surveys, process studies, time series studies, investigations of the sedimentary record and continental margin boundary fluxes, and the JGOFS data management system.

No. 24
The report presents the main findings of the joint Working Group of the IGBP and the International Social Science Council on Land-Use/Land-Cover Change; it describes the research questions defined by the group and identifies the next steps needed to address the human causes of global land-cover change and to understand its overall importance. It calls for the development of a system to classify land-cover changes according to the socioeconomic driving forces. The knowledge gained will be used to develop a global land-use and land-cover change model that can be linked to other global environmental models.

No. 25
Land-Ocean Interactions in the Coastal Zone (LOICZ) Science Plan. Edited by P.M. Holligan and H. de Boois, with the assistance of members of the LOICZ Core Project Planning Committee (1993). IGBP Secretariat, Stockholm, 50 pp.
The report describes the new IGBP Core Project, giving the scientific background and objectives, and the four research foci. These are: the effects of global change (land and freshwater use, climate) on fluxes of materials in the coastal zone; coastal biogeomorphology and sea-level rise; carbon fluxes and trace gas emissions on the coastal zone; economic and social impacts of global change on coastal systems. The LOICZ project framework includes data synthesis and modelling, and implementation plans cover research priorities and the establishment of a Core Project office in the Netherlands.
No. 26
The Fontainebleau Workshop, July 1992, defined a strategy to initiate a global terrestrial monitoring system for the IGBP project on Global Change and Terrestrial Ecosystems, the French Observatory for the Sahara and the Sahel, and the UNESCO Man and the Biosphere programme, in combination with other existing and planned monitoring programmes. The report reviews existing organizations and networks, and drafts an operational plan.

No. 27*
A presentation of the mandate, scope, principal subjects and structure of the BAHC research plan is followed by a full description of the four BAHC Foci: 1) Development, testing and validation of 1-dimensional soil-vegetation-atmosphere transfer (SVAT) models; 2) Regional-scale studies of land-surface properties and fluxes; 3) Diversity of biosphere-hydrosphere interactions; 4) The Weather Generator Project.

No. 28*
This Report provides an overview of the global change research to be carried out under the aegis of the International Geosphere-Biosphere Programme over the next five years. It represents a follow-up to IGBP Report No. 12 (1990) that described the basic structure of the global change research programme, the scientific rationale for its component Core Projects and proposals for their development. The IGBP Core Projects and Framework Activities present their aims and work programme in an up-to-date synthesis of their science, operational and implementation plans.

No. 29
A summary is given of the conference arranged by the Global Change System for Analysis, Research and Training (START) on behalf of the IGBP, the Human Dimensions of Global Environmental Change Programme (HDP), and the Joint Research Centre of the Commission of the European Communities (CEC) that describe the global change scientific research situation in Africa today.
No. 30
This report sets out the goals and directions for GAIM and IGBP-DIS over the next five years, expanding on the recent overview of their activities within IGBP Report 28 (1994). It describes the work within IGBP-DIS directed at the assembly of global databases of land surface characteristics, and within GAIM, directed at modelling the global carbon cycle and climate-vegetation interaction.

No. 31
The workshop focused on interactions between African savannas and the global atmosphere, specifically addressing land-atmosphere interactions, with emphasis on sources and sinks of trace gases and aerosol particles. The report discusses the ecology of African savannas, the research issues related to carbon sequestration, ongoing and proposed activities, and gives a research agenda.

No. 32
The goals of IGAC are to: develop a fundamental understanding of the processes that determine atmospheric composition; understand the interactions between atmospheric chemical composition and biospheric and climatic processes, and predict the impact of natural and anthropogenic forcings on the chemical composition of the atmosphere. The Operational Plan outlines the organization of the project. The plan describes the seven Foci, their related Activities and Tasks, including for each the scientific rationale, the goals, strategies.

No. 33
LOICZ is that component of the IGBP which focuses on the area of the Earth’s surface where land, ocean and atmosphere meet and interact. The implementation plan describes the research, its activities and tasks, and the management and implementation requirements to achieve LOICZ’s science goals. These are, to determine at regional and global scales: the nature of these dynamic interactions, how changes in various compartments of the Earth system are affecting coastal zones and altering their role in global cycles, to assess how future changes in these areas will affect their use by people, and to provide a sound scientific basis for future integrated management of coastal areas on a sustainable basis.
No. 34
The Science Task Team discussed and developed recommendations for multi-Core Project collaboration within the IGBP under three headings: process studies in terrestrial environments, integrated modelling efforts, and partnership with developing country scientists. Three interrelated themes considered under process studies are: transects and large-scale land surface experiments, fire, and wetlands. Methods for implementation and projects are identified.

No. 35
The Science/Research Plan presents land-use and land-cover change and ties it to the overarching themes of global change. It briefly outlines what is currently known and what knowledge will be necessary to address the problem in the context of the broad agendas of IGBP and HDP. The three foci address by the plan are: (i) land-use dynamics, land-cover dynamics - comparative case study analysis; (ii) land-cover dynamics - direct observation and diagnostic models; and (iii) regional and global models - framework for integrative assessments.

No. 36
The IGBP Terrestrial Transects are a set of integrated global change studies consisting of distributed observational studies and manipulative experiments coupled with modelling and synthesis activities. The transects are organized geographically, along existing gradients of underlying global change parameters, such as temperature, precipitation, and land use. The initial transects are located in four key regions, where the proposed transects contribute to the global change studies planned in each region.

No. 37
This report was prepared by scientists representing BAHC, IGAC, and GCTE. It is a prospectus for an integrated hydrological, atmospheric chemical, biogeochemical and ecological global change study in the tundra/boreal region of Northern Eurasia. The unifying theme of the IGBP Northern Eurasia Study is the terrestrial carbon cycle and its controlling factors. Its most important overall objective is to determine how these will alter under the rapidly changing environmental conditions.
No. 38
This report summarizes the findings and recommendations of an International Geosphere-Biosphere Programme (IGBP) Workshop which aimed to develop an approach to modelling landscape-scale disturbances in the context of global vegetation change.

No. 39
This report is the major product of a three-day workshop entitled: “Modelling the Delivery of Terrestrial Materials to Freshwater and Coastal Ecosystems” held in Durham, NH, USA from 5-7 December 1994.

No. 40
Based on a draft plan written by the SCOR/IOC SSC for GLOBEC in 1994. That plan was itself based on a number of scientific reports generated by GLOBEC working groups and on discussions at the GLOBEC Strategic Planning Conference (Paris, July 1994). This document was presented to the Executive Committee of the Scientific Committee on Ocean Research (SC-SCOR) for approval (Cape Town, November 14-16 1995), and was approved by the SC-IGBP at their meeting in Beijing in October 1995. The members of the SCOR/IGBP CPPC were: B. J. Rothschild (Chair), R. Muench (Chief Editor), J. Field, B. Moore, J. Steele, J.-O. Strömberg, and T. Sugimoto.

No. 41
This report describes the strategy for the Miombo Network Initiative, developed at an IGBP intercore-project workshop in Malawi in December 1995 and further refined during the Land Use and Cover Change (LUCC) Open Science Meeting in January 1996 and through consultation and review by the LUCC Scientific Steering Committee (SSC).
No. 42
The Kalahari Transect is proposed as one of IGBPs Transects. It is located so as to span the gradient between the arid subtropics and the moist tropics in southern Africa, a zone potentially susceptible to changes in the global precipitation pattern.

No. 43
This report is the result of a workshop on IGBP mountain research issues held in Kathmandu, Nepal, from 30 March to 2 April 1996.

**Book of Abstracts**
This book of abstracts is a result of materials presented at the scientific symposium held in conjunction with the Fourth Scientific Advisory Council for the IGBP (SAC) held in Beijing, 23-25 October, 1995.

**IGBP Booklet**

**Global Change: Reducing Uncertainties**

**IGBP Directory**
IGBP Directory. No. 1, February 1994
IGBP Directory. No. 2, October 1995

**IGBP Newsletter**