SAGARMATHA

Snow and Glacier aspects of Water Resources Management in the Himalayas

Final Technical Report: Volume 1

Project Overview

by

Gwyn Rees, Caroline Sullivan and Dermot O'Regan

Centre for Ecology and Hydrology, Wallingford, UK

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DFID KAR Project No. R7980

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Executive Summary

While deglaciation is considered to be a world-wide problem, there is particular concern at the alarming rate of retreat of Himalayan glaciers. Some experts have speculated that the glaciers of the region will disappear within the next 40 years, resulting in widespread, catastrophic water shortages. In March 2001, the United Kingdom's Department for International Development (DFID) commissioned a project called SAGARMATHA (Snow and Glacier Aspects of water Resources Management in The Himalaya), *"to assess the seasonal and long-term water resources in snow and glacier fed rivers originating in the Hindu Kush - Himalayan region and to determine strategies for coping with the impacts of climate-change induced deglaciation on the livelihood of people in the region."*

An international team of hydrologists, glaciologists and environmental economists was gathered to undertake the project. A new regional hydrological model was developed to give forecasts of annual and seasonal river flows for a period of up to 100 years for a variety of climate change scenarios. Results suggest that, for many areas, the catastrophic water shortages forecast by some experts are unlikely to happen for several decades, if at all. The threat that the glaciers of the Himalayas will vanish within 40 years was considered to be ill-founded. The results further showed that the impacts of deglaciation vary considerably within the region and within catchments. Highly glaciated catchments, and catchments where melt-water contributes significantly to the runoff, appeared to be the most vulnerable to deglaciation. The model identified certain areas, such as in the Upper Indus, where deglaciation may, indeed, result in a significant reduction of river flows within the next few decades. This would have serious consequences for future water availability in these areas, and measures to mitigate the impacts should be considered urgently.

An assessment of the impacts of deglaciation on the livelihood of communities was conducted at three spatial scales: at a community level; at a basin level; and regionally. This consultation-based activity identified the potential threats from deglaciation and suggested possible strategies for adapting to them. It concluded that, while millions of very poor people may be affected by significant changes in water

availability, people living at higher altitudes are most likely to be effected by deglaciation. Many adaptation strategies were identified that were applicable at the different scales, including: changing cropping patterns; increasing crop diversity; changing, animal husbandry techniques; improved water saving; building public awareness of climate-change; improving systems of data collection; developing sustainable water management and planning strategies; and improving communication and infrastructure in mountain areas. The recommendations have been summarized in two Policy Briefing Notes that will be distributed to policy makers throughout the region.

It is hoped that the planned dissemination of the project's outputs will raise awareness among policy makers, planners and decision makers in the region, and will help them to adapt appropriately to the impacts of deglaciation and, hence, safeguard the livelihoods of the many millions of people who rely on the melt-water resources of the Himalayas.

This first volume of the Final Technical Report provides a brief outline of the project and its findings. The Policy Briefing Notes and software, displaying the results of the regional hydrological model, are provided in the Annexes. Two additional volumes present a more detailed account of the two key aspects of the project: the hydrological assessment of the impacts of deglaciation on the water resources of the region; and the livelihood analysis respectively. A fourth volume contains various supplemental "Background Papers".

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- Mr. Shiba Prasad Rijal and Dr. Narendra Khanal of Tribhuvan University, Kathmandu;
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- The Land and Water Development Division of the Food and Agriculture Organization of the United Nations, Rome, for the Digital Soil Map of the World;
- The Hadley Centre for Climate Prediction and Research, for the HadRM2 regional climate model data;
- Environmental Systems Research Institute, Inc. (ESRI), USA, for the Digital Chart of the World;
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The project was undertaken as an activity of the Snow and Glacier Group of the Hindu Kush – Himalayan FRIEND[1] project, and, as such, is a contribution to the 6th International Hydrological Programme (IHP-VI) of UNESCO.

[1] FRIEND: Flow Regimes from International Experimental and Network Data

1 Introduction

There is compelling evidence that deglaciation is a widespread problem (Worldwatch News Brief, 2000). More than half of humanity relies on the fresh water that accumulates in mountains (Mountain Agenda, 1998) and the apparent global wastage of glaciers (Dyurgerov and Meier, 1997) has led to warnings of serious consequences for water resources around the world (IPCC, 1996; WGMS, 1998). Growing populations, intensifying agriculture, increasing urbanization and industrialization have led to a fourfold increase in global freshwater abstractions since 1940. To avoid a water crisis over coming decades, good understanding and management of mountain water resources is essential to satisfy such growing demands.

The alarming rate of retreat of Himalayan glaciers is of particular concern (Down To Earth, 1999). Several scientific papers report accelerated retreat over the last twenty years in Nepal and Bhutan (e.g. Fujita *et al.*,1997 & 2001; Kadota *et al.*, 1997 & 2000; Ageta *et al.*, 2001), while in India, over a similar period, one of largest glaciers in the Himalayas, the Gangotri glacier, has retreated approximately 850 metres, compared to the 2 km it has retreated in the last 200 years (Naithani *et al.*, 2001). Recent photographs show the extent of deglaciation of a single glacier, the Lirung Glacier, in Central Nepal between 1985 and 2003 (see Figure 1.1 (a) & (b)). With the inverted triangle serving as a common reference point in both, notice how, in Figure 1.1(b), the lower, debris covered, part of the glacier has detached from its upper part and has, thus, become a mass of “dead ice”, which is retreating rapidly. Similar behaviour has been observed throughout the Himalayas (Figures 1.2 to 1.4), and this has led some experts to predict that "glaciers in the region will vanish within 40 years as a result of global warming" and that the flow of Himalayan rivers will "eventually diminish, resulting in widespread water shortages"(New Scientist, 1999; BBC, 1999).

Figure 1.1 (a) *The Lirung Glacier in 1985*

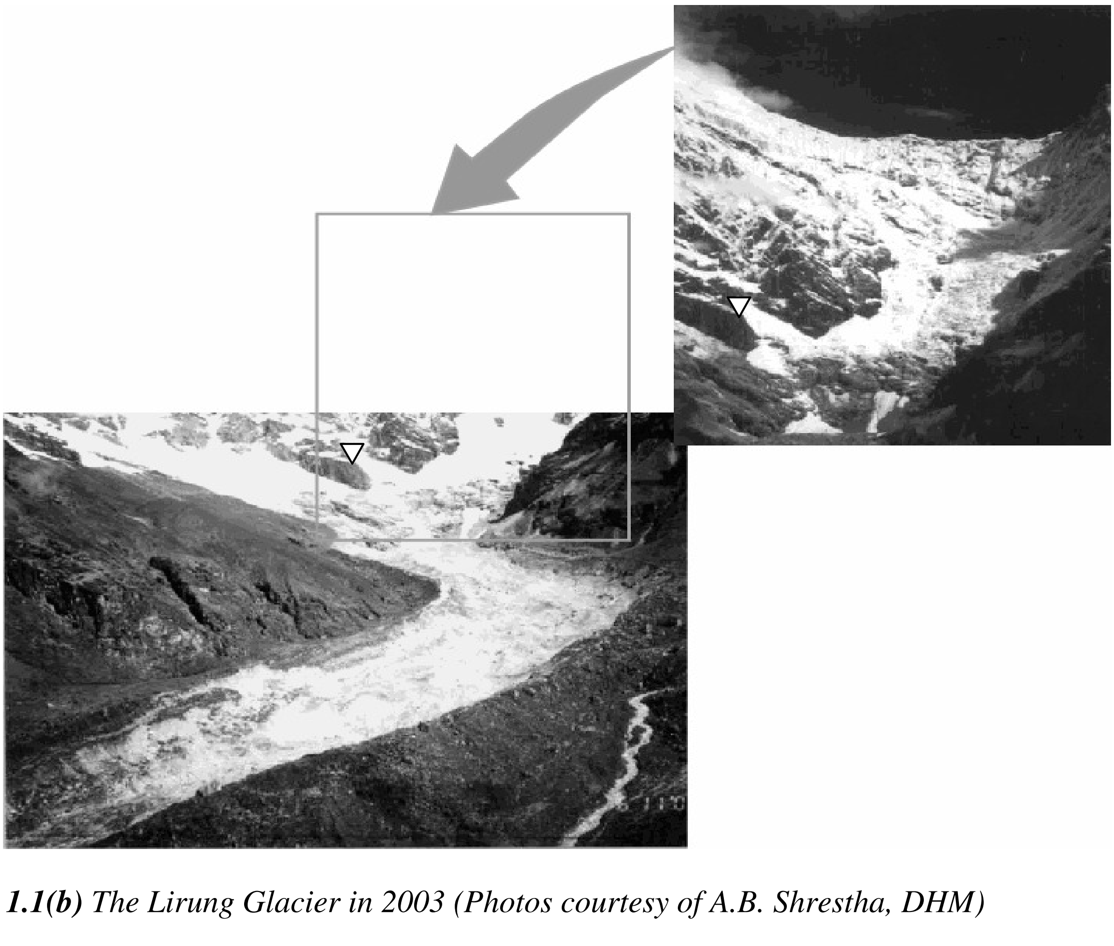

Figure 1.1(b) *The Lirung Glacier in 2003 (Photos courtesy of A.B. Shrestha, DHM)*

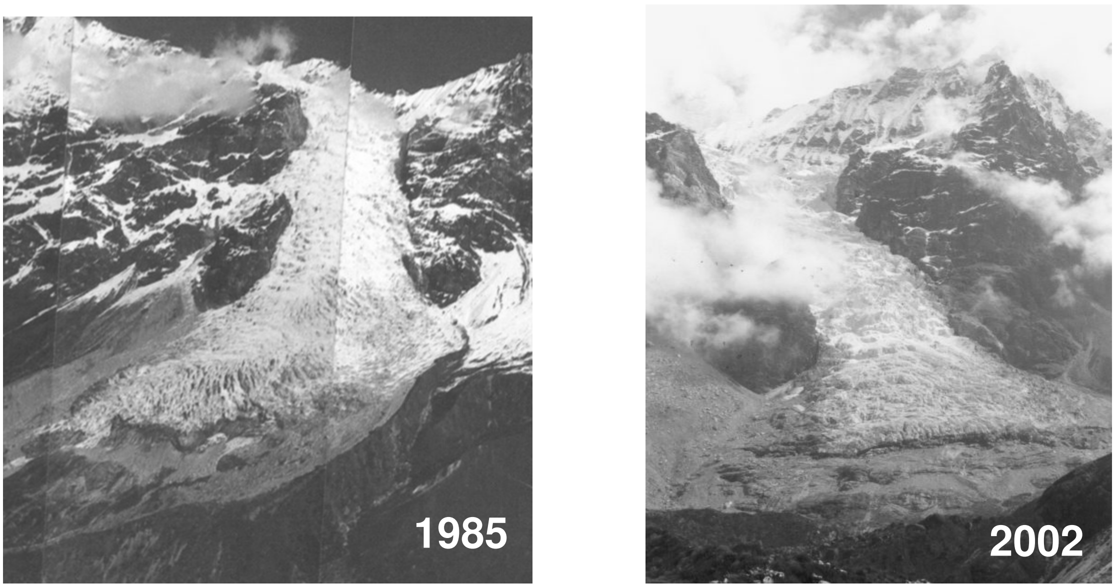

Figure 1.2 *Retreat of the Khimsung Glacier, central Nepal, 1985- 2002*

Figure 1.3 *Retreat of the glacier AX10, eastern Nepal, 1978 - 1996*

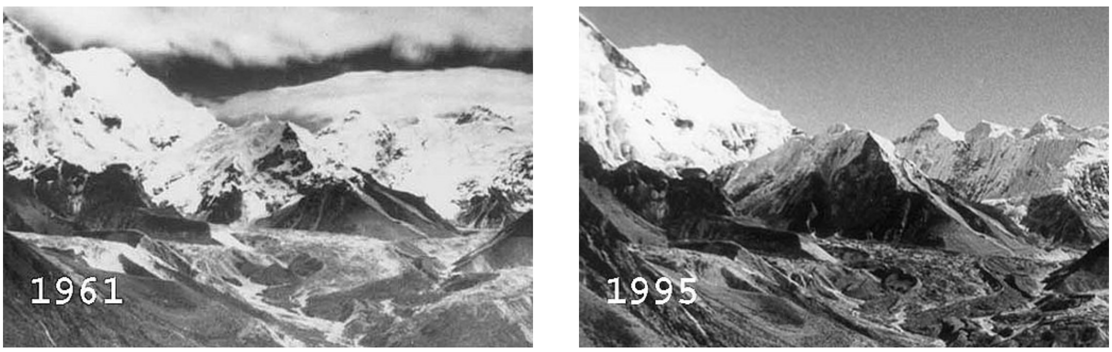

Figure 1.4 *Retreat of the Khumbu Glacier(Everest), eastern Nepal, 1978 – 1996*

(Photos courtesy of A.B.Shrestha, DHM, Nepal)

Deglaciation has potentially serious implications for the 500 million, or so, inhabitants of the Indus, Ganges and Brahmaputra river basins who rely on the snow and ice-melt from the mountains for up to 90% of the water to irrigate their crops. With water scarcity already prevalent in parts of these basins, the prospect of further water shortages has dire consequences not only for food production but also for the economy of the region as a whole. Although it is generally accepted that glacier retreat is likely to lead to a temporary increase, followed by a reduction, of river flows, there have been few attempts to estimate the timing of these and the volume of water concerned.

In response to this, the Centre for Ecology and Hydrology (CEH) assembled an international team of hydrologists, glaciologists and environmental economists to assess the long-term impact of deglaciation on the water resources of the Hindu Kush – Himalayan region. A proposal for a three-year research project was prepared and submitted to the Knowledge and Research Programme (KAR) of the Department for International Development (DFID) in September 1999. The project was given the title SAGARMATHA - "Snow and Glacier Aspects of water Resources Management in The Himalaya" - the Nepalese name for Mount Everest. The purpose of the project was "*to assess the seasonal and long term water resources in snow and glacier fed rivers originating in the Himalayan region, and to determine strategies for coping with impacts of climate change induced deglaciation on the livelihood of people in the region*"; its goal: to contribute to Theme W1 – *Improved assessment, development and management of water resources* – of the KAR programme.

The project was arranged into two key work-packages: one, to undertake a hydrological assessment of the potential effects of deglaciation to future water resources availability; the other, to study the possible livelihood impacts and to identify appropriate adaptation, or coping, strategies. The work was conducted over a period of 36 months, and culminated in a series of four stakeholder consultation workshops, held in Nepal and India during March and April 2004, where the outcomes of the project were presented to over 100 local people having interest in water resources management, albeit from a variety of different perspectives.

This report, the first volume of a four-part Final Technical Report (FTR), presents a general overview of the SAGARMATHA project, the results of its work-packages and the outcome of the stakeholder consultations. Volumes 2 and 3 provide a more detailed account of the hydrological assessment and livelihood impacts aspects of the project respectively, while the fourth volume, "Background Papers", includes the various interim progress reports and technical documents produced during a course of the project.

In this volume, "Volume 1: Project Overview", the project is summarized in six chapters. Following this Introduction, the next chapter (Chapter 2) describes the implementation of the project, from the composition of the project consortium to the methods and approach for achieving the project's objectives. Chapter 3 describes the new regional hydrological model that was developed during the project and presents a synthesis of the results obtained from running the model with various climate change scenarios. Chapter 4 outlines the livelihood impact analyses and proposes a series of potential adaptation strategies that evolved from the various surveys conducted and the consultations with local stakeholders. Plans for the dissemination of the project's outputs are outlined in Chapter 5, while the final chapter (Chapter 6) presents the conclusions of the project. Four annexures are provided: first, the Logical Framework for the project, which formed the basis of the contract between DFID and CEH; second, the final Output to Purpose Summary (OVI) Report for the project; third, a pair of Policy Briefing Notes that developed from the stakeholder consulations; and, finally, a CD-ROM and User Guide, which enable the results hydrological analysis to be viewed in a user-friendly software package.

2 Project Implementation

2.1 Introduction

This chapter outlines how the SAGARMATHA project was undertaken. It reiterates the objectives of the project and describes the resources that were available, the composition of the project team, the management of the project, and the project's activities and outputs.

2.1 Aims and objectives

The general aim of the SAGARMATHA project was to make an objective assessment of the impacts of deglaciation on the future water resources in the Indus, Ganges and Brahmaputra river basins, and to establish how downstream communities would cope with any changes in water availability. It was intended that the outcomes of the project would create awareness among policy makers, planners, decision makers and water-users on the extent of the threat, and identify appropriate strategies to mitigate the impacts. The overall *purpose* of the project was formally stated as: *"to assess the seasonal and long term water resources in snow and glacier fed rivers originating in the Himalayan region, and to determine strategies for coping with impacts of climate change induced deglaciation on the livelihood of people in the region"*. As such, its *goal* was to contribute to Theme W1 – *Improved assessment, development and management of water resources* – of the DFID Knowledge and Research (KAR) programme.

2.2 Time-scale and funding

The project was planned to have a duration of 36 months, from a nominal start-date of 1 April 2001, with DFID providing a total financial contribution of £315,000.

2.3 Project Team

The project was undertaken by a multi-disciplinary team of hydrologist, glaciologists, environmental economists and software developers from organizations in Nepal, India and the United Kingdom. The project was led by the Centre of Ecology and Hydrology (CEH), Wallingford, UK, a government research institute with over 30 years' experience in hydrological research and water resources management in developing countries. From Nepal, two organizations were formally involved in the project as sub-contractors to CEH: the Department for Hydrology and Meteorology (DHM), a government department responsible for the national hydrometeorological monitoring network, flood forecasting and other operational hydrology matters; and the International Centre for Integrated Mountain Development (ICIMOD), an international non-governmental organization concerned with the social and economic development of the Hindu Kush - Himalayan region. The Department of Geography at Tribhuvan University (TU), Kathmandu, also participated in an informal capacity, by supplying a PhD student to work on the project. From India, the Glacier Research Group at Jawaharlal Nehru University, which specializes in Himalayan glaciology, was also involved as a sub-contractor, as too was the School of Environment and Life Sciences (Alpine Glacier Research Project) of the University of Salford, UK, which has over 20 years' experience of glacier research in the Alps and the Karakoram.

The project was arranged into two main work-packages. The one work-package focused on the hydrological aspects of the project, assessing the potential effects of deglaciation on future water resources availability. The other work-package studied the possible livelihood impacts of deglaciation and attempted to identify appropriate adaptation strategies for communities that might be affected. Activities in either work-package were assigned to members of the project team, according to their expertise. Regular communication between those involved in each ensured that both work-packages progressed properly towards the common goal of the project.

The project, as a whole, was managed by Mr. Gwyn Rees, a hydrologist at CEH who has previously led several DFID projects in the region. Mr. Rees, supported by Dr. Rob Lamb, Dr. Alan Gustard, Ms. Heather Musgrave and Dr. Andy Young at CEH, was also responsible for the "hydrological assessment" work-package. Others who contributed to the work-package included: Mr. Adarsha Pokhrel (Hydrologist, Director General) and Dr. Arun Bhakta Shrestha (Senior Glaciologist) at DHM; Prof. Syed Hasnain (Glaciologist, Senior Professor), Dr. Rajesh Kumar (Glaciologist) and Mr. Shrest Tayal (PhD student) at JNU; and Prof. David Collins (Glaciologist, Professor of Physical Geography) and Mr. Nick Pelham (PhD student) at the University of Salford.

The “livelihood impacts” work-package was led by Dr. Caroline Sullivan, an environmental economist and Head of the Water Policy and Management Group at CEH. Supported by Mr. Dermot O’Regan at CEH, she coordinated the contributions from Ms. Mandira Shrestha (Water Resources Specialist) and Dr. Binayak Bhadra (Economist, Deputy Director) at ICIMOD, and Mr. Shiba Prasad Rijal, a PhD student at TU. Mr. Rijal’s research was supervised jointly by Dr. Narendra Khanal, a lecturer of geography at TU, Dr. Bhadra and Dr. Sullivan.

As stated in the contract, three full-time PhD students were supported during the course of the project. At JNU, Mr. Shrest Tayal was supported in his studies of the “Sub-glacial Hydrology of the Gangotri Glacier”, at the headwater of the Ganges in the Garhwal Himalaya. As mentioned earlier, Mr. Shiba Prasad Rijal is undertaking a PhD study at TU on “Water and livelihoods in Mountain Areas: A case of Modi Watershed, Nepal”, as a contribution to the “livelihood impacts” work-package. Meanwhile, Mr. Nick Pelham, at the University of Salford, received project support for his research into the development of a generic glacier-melt model, providing input to the project’s new regional hydrological model. All three are due to submit their theses within the next 12-18 months. During the course of the project, Mr. Gwyn Rees also registered to undertake a part-time PhD at the University of Salford on the “Impact of Deglaciation of the Water Resources of the Himalaya”. None of the costs associated with his study were borne by the project.

The project benefited further from inputs from staff at CEH and other experts externally. The contributions from these individuals are acknowledged at the beginning of the report.

2.4 Contract negotiation and management

DFID notified CEH that the SAGARMATHA project would be funded in December 2000. Contract documents were issued at the end of March 2001, and, following a period of negotiation, the contract was eventually signed in August 2001, some 5 months after the project was due to have started. In the meantime, CEH began negotiating the sub-contracts for the other team members, finalising their role in the project, the resources they would receive, and the deliverables expected from them. As with the main contract, delays were encountered in agreeing some of the sub-contracts. In particular, Nepalese government regulations, which initially appeared to prevent DHM from being a sub-contractor, had to be overcome. Following discussions with the parent ministry, a Memorandum of Understanding between DHM and CEH was approved by the Minister of Science, allowing DHM to formally participate in the project. All sub-contracts were signed by January 2002.

As well as fulfilling their technical obligations, the sub-contractors were required to submit six-monthly financial and progress reports to CEH. CEH, in turn, were obliged to submit a financial statement and interim progress report with the same periodicity to DFID. Copies of the interim progress reports submitted can be seen in the "Background Papers" volume (Volume 4). The progress of the project was also reported to DFID each year at the annual CEH/DFID KAR Review Meetings in Wallingford.

Sub-contractors were required to submit invoices six-monthly in arrears for all allowable expenses, other than for capital expenditure items, which could be invoiced for in advance. CEH was responsible for collating and checking all sub-contractor invoices, issuing the main project invoices at regular intervals to DFID, and for the subsequent disbursal of payments.

2.5 Progress monitoring

Progress was continuously monitored for the duration of the project by a variety of means. Sub-contractors routinely submitted progress reports of their activity and expenditure every six months (September and March). Project meetings, involving all project participants, were held each year: the first, in Kathmandu in October 2001; the second, in New Dehli in November 2002; and the third, in Wallingford in October 2003. All issues and actions arising from the meetings were formally recorded in the Meeting Minutes and distributed to participants shortly after. Copies of the minutes can be seen in Volume 4 of the FTR. As well as the formal general project meetings, participants met frequently to discuss their work on specific activities. Participants also communicated regularly via e-mail, or telephone, and, where necessary, conducted visits of up 4 weeks to each other's organizations. The project manager maintained a general view of progress by regularly updating the project's Microsoft Project-based work-plan.

Despite these efforts, some activities took longer than expected, causing the delivery of their outputs to be later than initially agreed. Although some delays were simply a consequence of an initial under-estimation of the required effort and/or time, certain activities were effected by circumstances beyond the control of the project. In particular, Maoist insurrection and civil unrest in Nepal posed considerable difficulties to the project. In November 2001, a State of Emergency was declared in Nepal, which prevented Mr. Rijal from carrying out essential field-work for several months; and Maoist activity in the vicinity of the project's "study" catchment in the Kaligandaki river basin has since continually hindered his work. A visit by CEH staff to Kathmandu in November 2002 was cancelled after a spate of bombings in tourist areas of the city, while unrest in Kathmandu and a general strike (*bandh*) in Pokhara threatened to disrupt the recent stakeholder consultation workshop there.

2.6 Activities and Outputs

The project was carefully planned so that the workload was distributed fairly between team members. The project comprised 8 key activities, which, for ease of management, were arranged into two major work-packages. Activities were allocated to according to the relevant expertise of the team members. A single "lead" organisation was assigned to each activity, with responsibility for co-ordinating tasks within the activity and ensuring the timely delivery of agreed outputs. A list of the activities that comprised the project is given in Table 2.1, together with a summary of the eventual outputs and their verification. The same activities appear in the Logical Framework shown in Annex 1, which formed the contractual basis of the project. The final "Output to Purpose Summary Report" for the project is given in Annex 2.

All partners contributed to the literature review and appraisal of methods (Activity 1), which were brought together into the project's Inception Report. The project database of hydrometeorological and relevant spatial data (Activity 2) was built at CEH, with contributions from DHM and JNU. Additional glacier-data, from existing monitoring stations, was also collected by DHM and JNU, and forwarded to CEH. Data from glaciers in the Karakoram were supplied by the University of Salford. On completion, an instance of the database was distributed to the work-package participants in November 2002.

***Table 2.1** Activities and outputs of the SAGARMATHA project*

Activity	Output	Verification of output
1 **Inception study** a) literature review of methods b) identify available data	Inception report	Inception Report produced in March 2002, approved by DFID September 2002; to be made available on project WWW site
2 **Build project database** a) define database structure and populate database with data	Project database	Database described in Technical Note 1, and distributed to project participants in November 2002.
b) provide field equipment	Glacier monitoring equipment for India and Nepal	2 AWS purchased and installed at glaciers in India and Nepal by summer 2002
3 **Develop regional hydrological model**	Regional hydrological model	Regional hydrological model developed, described in Technical Note 2, April 2004
4 **Apply regional hydrological model** a) derive flow accumulation grid b) apply contemporary data and climate change scenarios	Water resources forecasts	Results published in Technical Report, distributed at stakeholder workshops in April 2004, and feature in Volumes 1 & 2 of this Final Technical Report
5 **Software development** a)define software requirements b)implement regional model in software package by JNU c) beta-test software d) package software on CD and produce User Guide	Software package	Software Requirements Specification produced March 2003. Software tested April 2004. Software and User Guide to be made available on request via project WWW site.
6 **Assess of impacts on livelihoods & development of adaptation strategies** a)appoint local phd student to help investigate impacts of deglaciation on livelihoods. b)establish contact with stakeholders, initiate consultations c)qualitatively analyse water resource usage: fact-find and consultation with stakeholders d)assess impacts of changes in water resources using model forecasts	Livelihood impacts report	Results of stakeholder surveys presented at consultation workshops in March & April 2004
e)develop coping strategies to mitigate impacts f) finalise adaptation strategies	Adaptation strategies	Adaptation strategies, finalised following consultation workshops, feature in Volumes 1 & 3 of this Final Technical Report
7 **Knowledge transfer** a)prepare and conduct 2 workshops for local stakeholders	Knowledge transfer to local stakeholders	3 stakeholder consultation workshops held in March & April 2004.
b)develop www site for technical reports and other project information c)disseminate results in international programmes, journals and conferences	Knowledge transfer to international community	Technical reports to be posted on the project WWW site. Papers planned for publication in coming months.
8 **Project management**	Progress reports, minutes of meetings, Final Report	Minutes of meetings, progress reports available in Volume 4 of FTR

Project resources enabled JNU and DHM to purchase 2 new Automatic Weather Stations (AWSs) in order to support their continued long-term monitoring of the Gangotri and Lirung glaciers respectively. Further details of the project database and the AWSs are given in the next chapter of this report.

The development of the snow/glacier model (Activity 3) was conducted jointly by CEH, the University of Salford, DHM and JNU. The regionalisation activity (Activity 4), to adapt the snow/glacier model to a regional runoff and routing model, was conducted by the same team. The development of the models and the results are described in the next chapter and, more fully, in Volume 3.

The implementation of model results in a user-friendly software package (Activity 5) was assigned to JNU. A User Requirements Specification was drawn-up during a visit by JNU staff to CEH in February 2003, and the software was subsequently developed in India. Unfortunately, delays with the development meant that the software had not been thoroughly tested prior to the stakeholder consultation workshops and, therefore, it was not possible to distribute it, as had been planned, at the workshops. The software was, however, demonstrated at the workshops, and comments from participants have since been incorporated. The software has now been tested, and will be freely available, on request, via the project world-wide-web site. The proposed link, within the software, between the hydrological forecasts and potential adaptation strategies was omitted, on the recommendation of DFID (CEH/KAR Review Meeting, 2002), because it was considered that users might misinterpret the recommendations.

The social and economic impacts of deglaciation on livelihoods in the region were the focus of Activity 6, involving CEH, ICIMOD and TU. A summary of the activity and its outcomes is given in Chapter 4 of this volume, and in the accompanying Volume 3. The dissemination of the project's outputs (Activity 7) is led by CEH, but involves all project participants. Some dissemination activities, such as the implementation of the project WWW site and the recent stakeholder consultation workshops have already been conducted. Details of these and other planned activities are given in Chapter 5.

3 An assessment of the impacts of deglaciation on water resources

3.1 Introduction

Melt-water from the Himalaya is an important component of the flow of the Indus, Ganges and Brahmaputra rivers, and the disappearance of glaciers is expected to have a significant impact on water resources availability in each of the three the basins. The SAGARMATHA project aimed to quantify these impacts by developing the first regional hydrological model that was capable of representing the fluctuation of glaciers across the entire Himalayan range. The model provides estimates of discharge (river flow) at any point in the study area (Figure 3.1). The model was first applied using standard period (1961-90) climate data, to provide baseline estimates of average annual and seasonal flow, and, then, with a variety of climate change scenarios for a future period of up to 100 years. Comparison between climate change and baseline estimates indicated potential future changes of water resources availability.

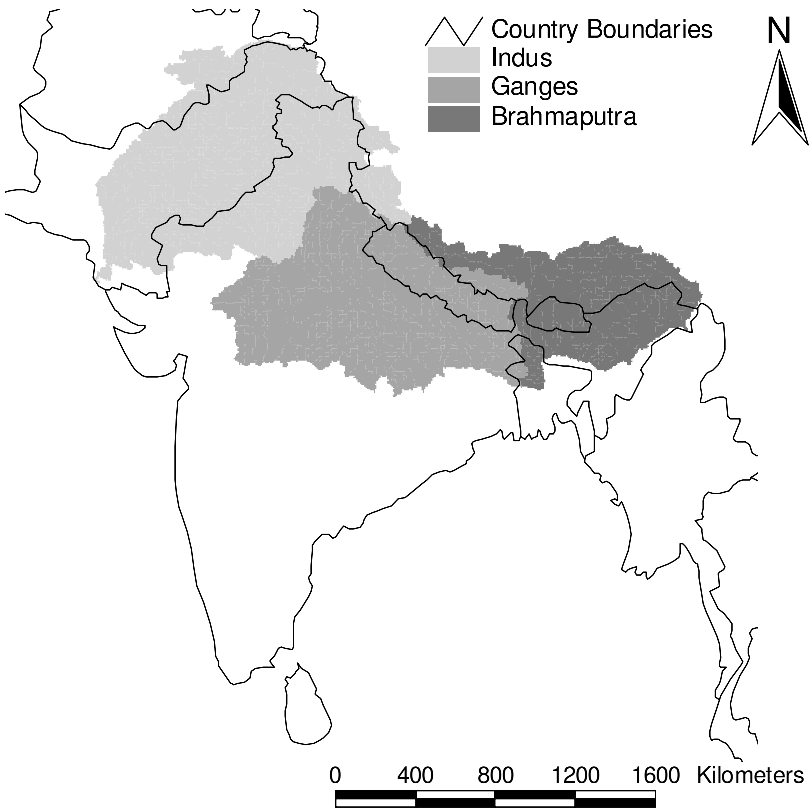

Figure 3.1 *The SAGARMATHA study area*

This chapter provides an outline of the development of the regional hydrological model and provides an analysis of the results obtained from it. The chapter first describes the conceptual design of the regional model and reviews the data that was obtained for its implementation. The various parts of the model are then described, including the innovative dynamic glacier-melt component. The regional model was applied with nine different climate change scenarios; these are described and comparisons are made between the model outputs, or forecasts, at four "focal areas" – the Upper Indus, the Ganges river system in India, the Narayani basin in Nepal and the Upper Brahmaputra. The chapter concludes with an analysis of the model results. A more detailed account of the "hydrological assessment" described in this chapter is given in Volume 2, "An assessment of the hydrological impacts of deglaciation in the Himalayas", of the FTR.

3.2 Model concept

Following an assessment of various modelling approaches (See "Inception Report" in Volume 4), it was decided that the best way to represent present and future water resources in the study area would be by means of a semi-distributed, physically-based macro-scale model. A "macro-scale model" is defined as a hydrological model that is capable of being applied, without calibration at the catchment scale, over a large geographic domain (Arnell, 1999*a*). The new regional hydrological model developed in the project was based on the macro-scale model described by Arnell (1999*b*), which provided grid estimates of average annual runoff, at a spatial resolution of 0.5° x 0.5° for the entire globe, using data from the Climate Research Unit (CRU) at the University of East Anglia (New *et al.*, 2000) as inputs to a modified form of the CEH Probability-Distributed Model (PDM) (Moore, 1985). The model was redefined in the project to provide estimates of average annual and seasonal runoff for grid cells at a 20km by 20km resolution for the Indus, Ganges and Brahmaputra river basins. A schematic of the intended application of the model is shown in Figure 3.2. The model is a GIS-based model, with its outputs (i.e. estimates of annual and seasonal runoff, in mm) available as ArcGIS grid coverages. The estimates of runoff were then converted to river flows (m^3/s) by means of a 1 km flow accumulation grid derived from a 1 km resolution digital elevation model (DEM).

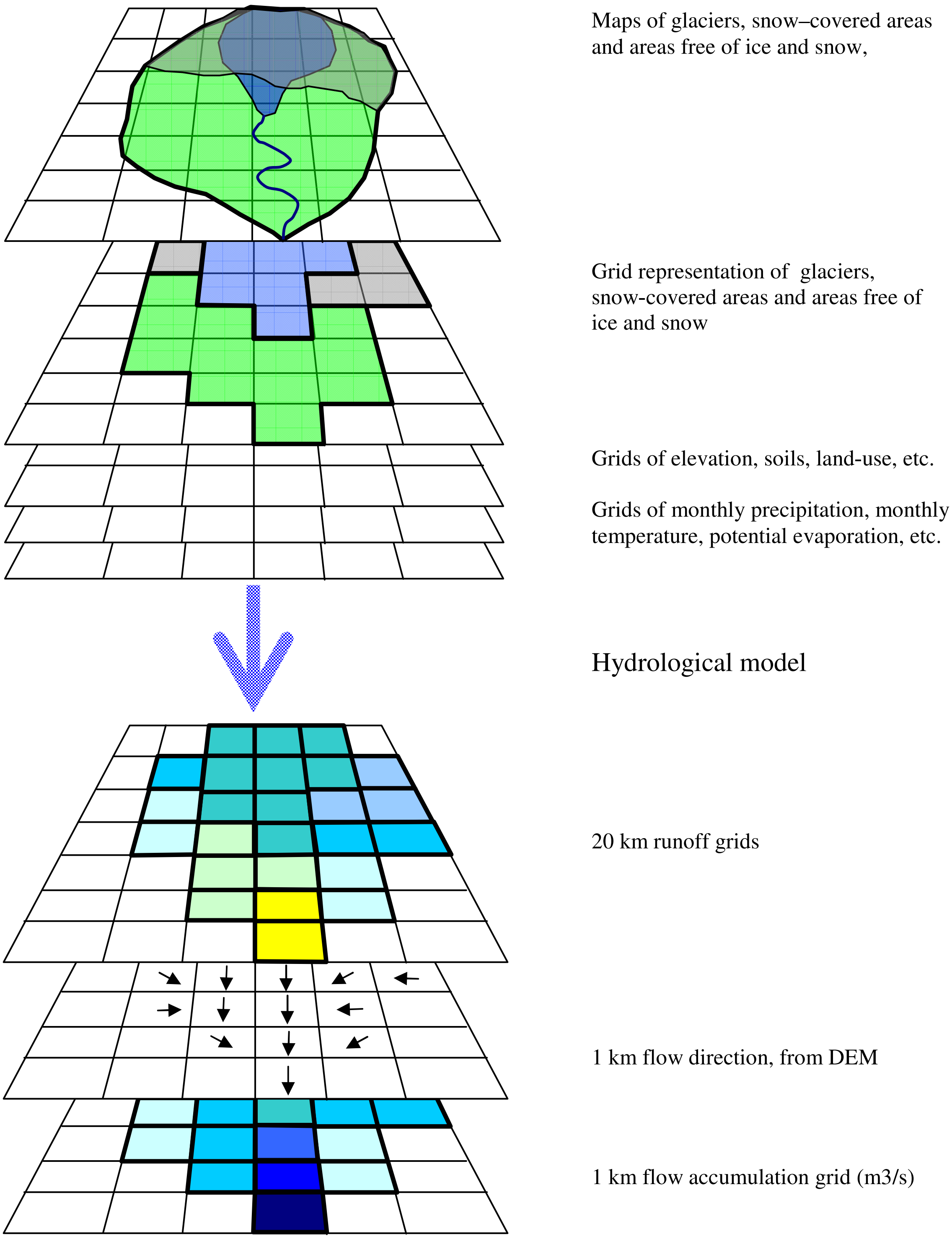

Figure 3.2 *Concept of the regional hydrological model*

3.3 Database development

To implement the model, a variety of spatial data were required to represent variations in the runoff-generating processes across the region. These included data that represent the region's climate (e.g. maps of monthly precipitation, temperature, etc.) and others that characterise the hydrological response of catchments, such as maps of land use, soils and topography. In addition to the spatial data, time-series data from point measurements were required for defining model parameters and validating output. A summary of the spatial data used as input to the model is given in Table 3.1.

***Table 3.1** Input data for the regional hydrological model*

Data type	Description	Derivation
Precipitation	12 average monthly values for the 1961-90 standard period	Derived from the CRU baseline climatology
Rain-days		
Temperature		
Potential Evapotranspiration		
Predominant soil type	Majority value (dominant) of 7-type soil classification	Derived from FAO Digital Soil Map of the World
Forest cover	Proportion of forest cover in cell	Derived from the USGS Eurasia Land Cover Characteristics Database
Minimum cell elevation	Minimum, maximum and mean elevation of 1 km cells within the 20 km x 20 km cell	Derived from the USGS' 1 km x 1 km HYDRO1k DEM
Maximum cell elevation		
Mean cell elevation		
Contributing glacier area	Area of glacier ice contributing runoff to a cell	Derived from ESRI Digital Chart of the World (DCW)
Proportion of ice	Proportion of cell that is covered by ice	Derived from the DCW
Minimum ice elevation	Lowest and highest elevation of contributing glaciers	Derived from the DCW and HYDRO1k
Maximum ice elevation		

The spatial data described in Table 3.1, were obtained from many different sources. The Spatial climatological data were obtained from the Intergovernmental Panel for Climate Change (IPCC) Data Distribution Centre at CRU. These included the 0.5° x 0.5° baseline dataset of climate variables (e.g. temperature, precipitation, rain day frequency and radiation), presented as monthly averages for the 1961-90 IPCC standard period. These were downscaled from their original 0.5° resolution to the 20 km grid resolution of the SAGARMATHA model in ArcGIS. Penman Monteith monthly Potential Evapotranspiration was calculated at the 0.5° resolution from variables in the CRU climatology, and then similarly downscaled to 20 km. For each basin, grids of average monthly precipitation, rain-days, temperature and PE were produced at the 20 km resolution and stored as 48 (4 variables x 12 months) separate files in ArcGIS readable format.

Data describing the distribution of soil types as a 5 arc-minute resolution globally were obtained in digital from the Food and Agriculture Digital Soil Map of the World and Derived Soil Properties (FAO, 1997). The dataset identifies 109 individual soil types condensed in to 26 major groupings, and provides additional miscellaneous information on land-use, inland water bodies and glaciers, slope, soil texture and permafrost.

The proportion of forest cover in each cell was obtained from the United States Geological Survey USGS Eursian Land Cover Characteristics database (USGS, 2002). The dataset provides remote-sensing derived land-cover data at a 1 km resolution, described according to the IGBP land classification, which has 17 classes of vegetation, including classes for desert, ice-caps and glaciers, and water bodies. The project also made extensive use of the Hydro1k Digital Elevation Model (DEM), which is available free-of-charge from the (USGS, 2001). Hydro1k is a 1 km hydrologically ratified DEM, which also includes layers of flow direction, flow accumulation, slope, and aspect.

Initial glacier cover, and the proportion of ice within each cell was derived from the permanent snow and ice layer of the Digital Chart of the World (DCW), which was developed by the Environmental Systems Research Institute (ESRI, 1993). The data consists of global geographical data on a 1:1 million scale, and was developed using US Defence Agency Operational Navigation Charts. Figure 3.3 shows extracts from both the Hydro1k and DCW datasets.

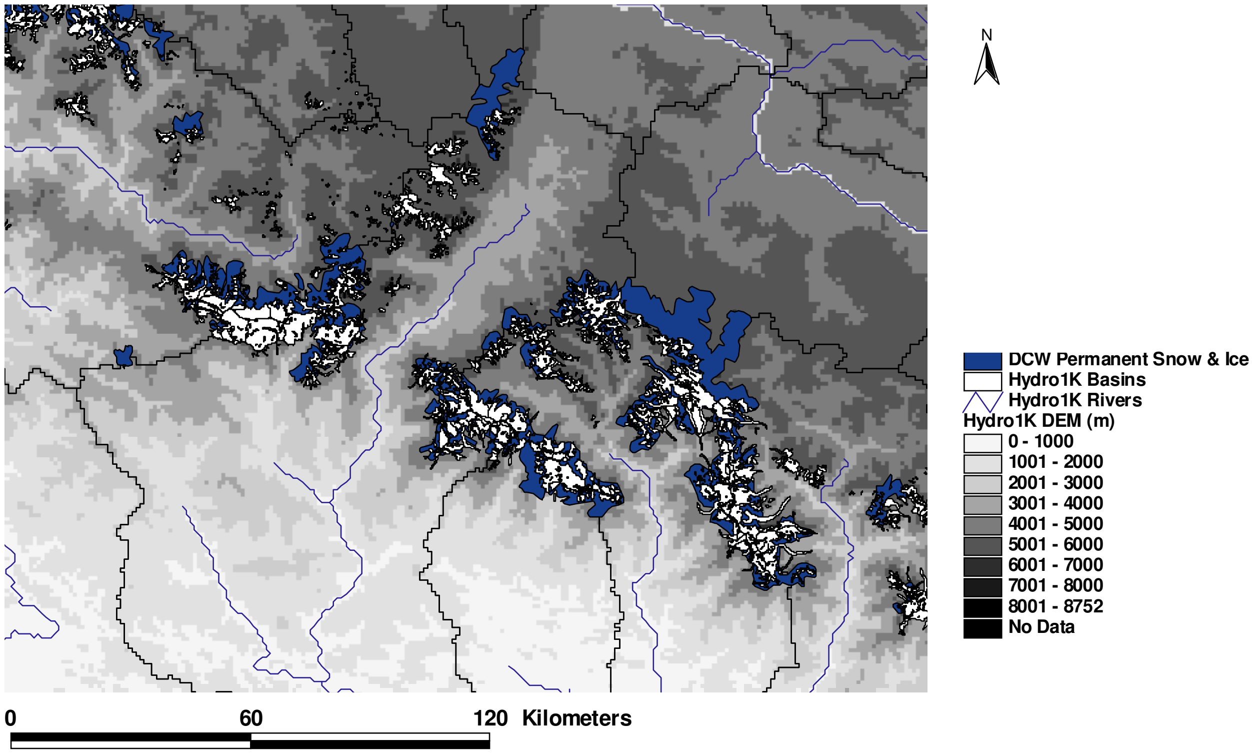

Figure 3.3 *Digital elevation model for the Himalayan region, including major rivers and areas of permanent snow and ice*

Obtaining access to hydrological and meteorological time-series data in the region was problematic, because of prevailing international tensions between countries. While DHM provided the project with data from the entire national hydro-meteorological network of Nepal, it proved more difficult to obtain data for India and Pakistan. The DHM data set includes daily flow data for 44 river gauging stations for the period 1964-2000, 258 daily precipitation records covering 1956-1996, 119 daily and monthly temperature records spanning the period 1934-1996, 114 records of average monthly humidity from 1967-1997, and 41 records with average monthly values of sunshine hours between 1967-1997. In contrast, the project only succeeded to directly obtain temperature and precipitation data from only four meteorological stations in India, for the period 1973-1999, and 10-day flow data for five river gauging stations on the Ganges river system. The project was, however, able to use 10-day flow data for 68 stations from the northern Indian state of Himachal Pradesh, which was obtained from an earlier DFID project (Rees *et al.* 2001). Similarly, data from Pakistan was obtained from earlier projects conducted there by project participants. The data includes monthly, 10-day and daily flow data for 20 river gauging stations with the earliest record dating back to 1960 and the latest to 1997, monthly precipitation data for 19 stations (1876 – 1999), and temperature data for 3 stations only (1958-98). Further time-series data were obtained from the WMO's Global Runoff Data Centre (GRDC) in Germany and the CRU. A summary of the hydrometeorological time-series data collected is given in Table 3.2.

***Table 3.2** Summary of hydrometeorological time-series data collected*

Data type		Country	Source of Data	Number of Stations	Temporal Resolution	Period of Data earliest – latest
Meteorological	Precipitation	Nepal	DHM	258	Daily	1956-1996
		India	JNU	4	Daily	1973-1999
			CRU	17	Monthly	1848-2000
		China	CRU	29	Monthly	1935-2000
		Pakistan	CRU	20	Monthly	1861-2000
			Various	19	Monthly	1876-2000
		Bangladesh	CRU	3	Monthly	1947-1998
		Afghanistan	CRU	1	Monthly	1961-1992
	Temperature	Nepal	DHM	119	Monthly	1934-1996
		India	IMD	4	Daily	1973-1999
		Pakistan	Various	3	Monthly	1882-1998
	Humidity	Nepal	DHM	114	Monthly	1967-1997
	Sunshine	Nepal	DHM	41	Monthly	1967-1997
Hydrometric (river flows)		Nepal	DHM	54	Daily	1963- 2000
		India	HP	68	10-Day	1964- 2001
			JNU	4	10-Day	1991- 2001
			GRDC	5	Monthly	1949- 1974
		China	GRDC	1	Daily and monthly	1956- 1982
		Pakistan	Various	14	Daily and 10-day	1960- 1997
			GRDC	6	Daily and monthly	1973- 1982
		Bangladesh	GRDC	4	Daily and monthly	1969- 1992

The time-series data described above provide a valuable insight to the general behaviour of the river systems and climate across the Himalaya. To understand the particular influence of glaciers on the region's rivers, data that describe conditions on or near the glacier are also important. Data from previous glacier studies in the regional were obtained by the project, as shown in Table 3.3.

Table 3.3 *Records available from previous glacier studies in the region of interest*

Location	Elevation m a.s.l.	Start date	End date	Variables	Resolution
Khumbu Glacier	5350	23/10/95	09/11/95	AT, SR, ST, WS, NR	1/2 hourly
Lingten Glacier		19/10/95	23/10/95	AT, SR, WS	1/2 hourly
Syangboche	3800	22/10/94	17/04/97	AT, ATM, ATm, SLT0.5, SLT15, RH, WS, WD, AP, SR, RSR, P	daily
Tsho Rolpa	4580	11/06/99	28/04/02	ATM, ATm, RHM, RHm, P, NR	daily
		09/06/99	28/04/02	AT, RH, WS, WD, NR	hourly
		09/06/99	28/04/02	AT, WS, WD, P, SD, LL, LLM, LLm, NR	hourly
		10/06/93	14/09/96	WS, WSM, WD, AT, RH, NR, AP, P	hourly
		12/06/93	29/05/96	WL, Q	hourly
Yala Glacier	5200	24/07/94	27/08/94	WL, P, DBT, WBT, RH, WS, WD, WTH, CL	8 hour
		24/08/92	20/09/94	P	hourly
		24/04/92	29/01/94	AT	1/2 hourly
Lirung Glacier	4190	05/06/02	14/07/02	RHM, ATM, WSM, WLM, SRM, RHm, ATm, WSm, WLm, RH, AT, WS, WD, WL, P, SR	daily
		06/06/02	01/07/02	P, NR	hourly
		06/06/02	01/07/02	RH, AT	6 hour
		09/06/02	30/06/02	ATM, Atm	daily
		04/06/02	14/07/02	RHM, ATM, WSM, WLM, SRM, RHm, ATm, WSm, WLm, RH, AT, WS, WD, WL, P, SR	hourly
		10/05/96	23/10/96	AT, NR, WS, P, RHM, RHm	hourly
		07/05/96	26/10/96	WL, Q	hourly
Langtang		18/06/87	31/12/98	WL, Q	daily
Kyang		01/06/02	08/07/02	P	daily
		01/06/02	08/07/02	NR	hourly
		01/06/02	01/07/02	RH, AT	6 hour
		01/06/02	30/06/02	ATM, ATm	daily
Dokriani		27/08/92	08/09/01	Q	
		07/13/99	08/09/01	P	
		05/08/94	09/08/01	AT	
		27/08/92	08/09/2001	water temp	
Chhota Shigri		24/8/86		Q, water temp	daily
		18/7/87		AT, RH, WS, P, Q	daily, hourly
		6/8/88		AT, Q	3 hour, daily

Key to Table 3.3

AT air temperature
AP atmospheric pressure
ATM max air temp
ATm min air temp
CL cloud
DBT dry bulb temp
LL lake level
LLM max lake level
LLm min lake level
NR net radiation
P precipitation
Q discharge
RH relative humidity
RHM max RH
RHm min RH
RSR reflected solar radiation
SD snow depth
SLT0.5 soil temp at 0.5 cm
SLT15 soil temp at 15 cm
SR solar radiation
SRM max solar radiation
ST surface temperature
WBT wet bulb temp
WD wind direction
WL water level
WLM max water level
WLm min water level
WS wind speed
WSM max wind speed
WSm min wind speed
WTH weather

To augment the historic glacier data collected, two new automatic weather stations (AWSs) were bought by the project. Both were installed at the beginning of the ablation season in 2002: one near the terminus of the Lirung Glacier in Central Nepal (Figure 3.4); the other, on the lower part of Gangotri Glacier in India (Figure 3.5). As well as providing data for the SAGARMATHA project, these AWSs represent a longer-term investment by supporting the continuing monitoring of the region's glaciers by DHM and JNU.

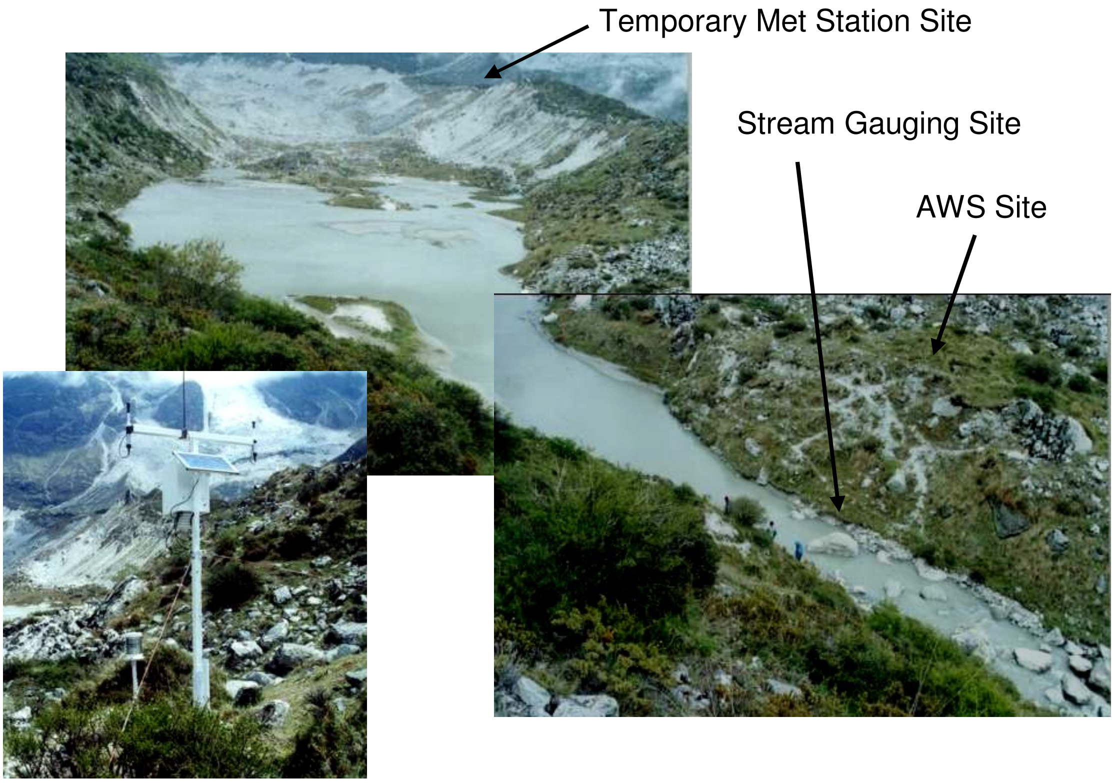

***Figure 3.4** AWS installed near the terminus of the Lirung Glacier, Nepal*

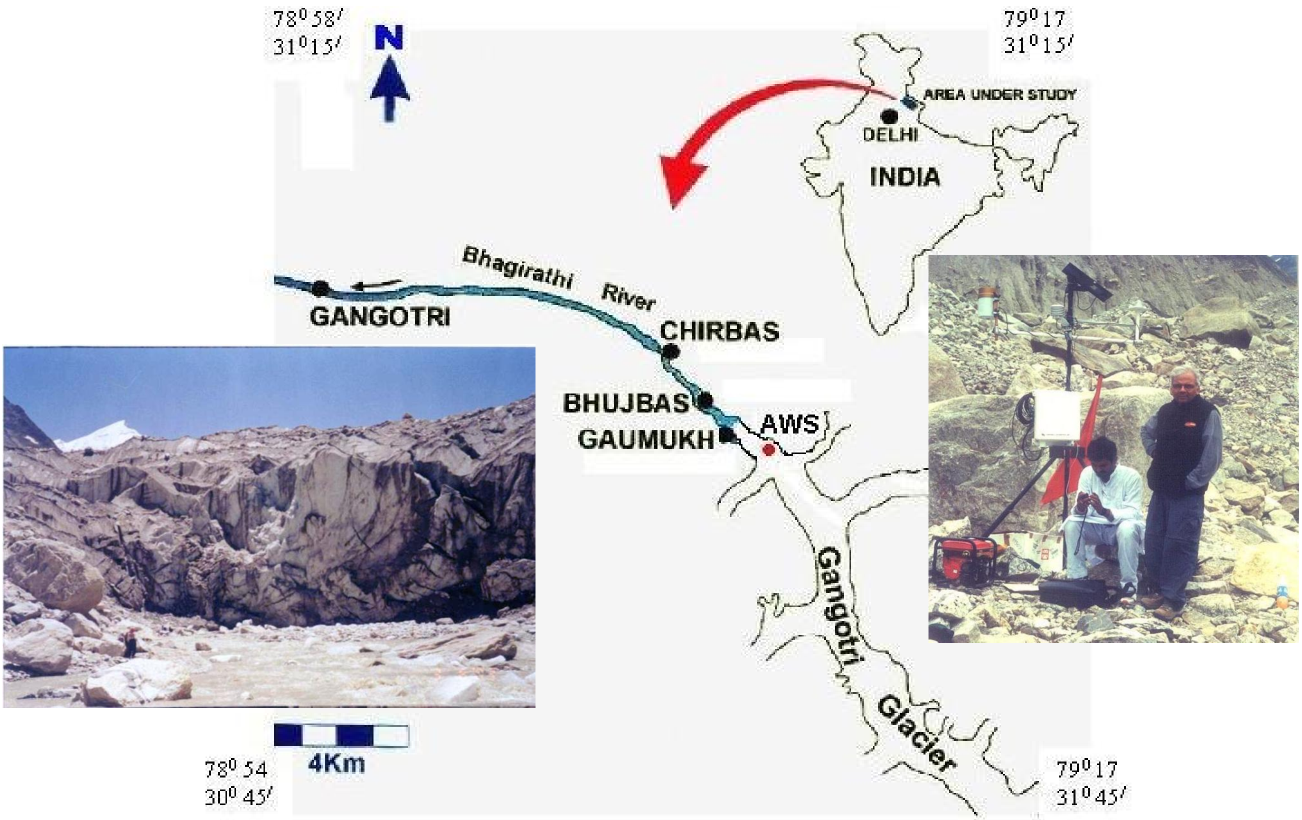

Figure 3.5 *Location of the AWS on Gangotri Glacier, showing (inset left) the snout of the glacier at Gaumukh , and (inset right) the AWS attended to by Prof. Hasnain and Dr. Kumar of JNU.*

3.4 The regional hydrological model

The SAGARMATHA regional hydrological model consists of three key components: a rainfall-runoff model; a snow-pack model, representing the build-up of snow and its subsequent melting; and an innovative glacier-melt model, for estimating the runoff contribution from many glaciers to a single grid cell.

3.4.1 The Rainfall-Runoff Model

The rainfall-runoff component was based on the Probability-Distributed Model (PDM), which was first developed at CEH in 1985 (Moore, 1985). The model used is an adaptation of the original, and was developed to be applied across a large geographical domain, such that, its parameters could be defined *a-priori* according to the spatial distribution of vegetation and soil types. The model regards each grid cell as an individual catchment, with no routing of runoff between cells. It takes a conceptual water balance approach to rainfall-runoff modelling, based on a soil moisture accounting procedure, and works at the daily time step. Daily rainfall and potential evaporation (PE) data are required as inputs to the model. These were derived from the CRU 1961-90 standard period monthly climatological data. Monthly values of Penman-Monteith PE, calculated from the CRU data, were disaggregated to daily values by simply dividing the monthly average equally between the number of days in each month. The monthly rainfall was distributed evenly between the average number of rain days for the respective month, with the occurrence of rainfall (the rain days) arranged randomly every year of the model run.

The model also requires information on soil properties and vegetation within each cell. The soil data were obtained from the Food and Agriculture Digital Soil Map of the World (FAO, 1997) and the vegetation coverage from the USGS Eurasian Land Cover Characteristics Database (USGS, 2002). The vegetation cover is required by the model to determine evaporation and soil moisture characteristics. The land cover data was also used to calculate the percentage cover of forest in each cell, while the soils information was used to calculate both the soil field capacity (the amount of water held in the soil against gravity) and soil saturation capacity (the amount of water held in the soil when all the pore spaces are full).

The PDM assumes a soil moisture store, with a capacity that varies across each cell, and a groundwater store. It works according to a simple accounting procedure, in which the soil moisture content (S_t) in the current period (day) is calculated as a function of the soil moisture content of the previous period (S_{t-1}), the rainfall (P_t) and the actual evaporation (AE_t). The soil moisture content is also reduced by direct runoff (Q_t) and the drainage of water from the soil into the groundwater store (D_t), as shown in Equation 3.1, with the final runoff determined as a function of Q_t and D_t.

$$S_t = S_{t-1} + P_t - AE_t - Q_t - D_t \qquad \text{…(3.1)}$$

3.4.2 The Snow-pack Module

The snow-pack module (Bell and Moore, 1999) was applied only to cells where the mean monthly temperature of any month descends below +3 °C. Daily temperature and precipitation data, together with mean, minimum and maximum elevation of the cell are the key inputs. Cells where snow was considered to occur were sub-divided into 10 equal-height elevation bands. With the mean daily temperature for the cell, T_{mean}, assumed to apply at the cell's mean elevation, the daily temperature in each elevation band, T_{band}, was calculated by a temperature lapse rate model, as follows:

$$T_{band} = T_{mean} + \alpha(z_{mean} - z_{mid}) \quad \text{...(3.2)}$$

where z_{mid} is the mid-elevation of the band and α the temperature lapse rate, which, following analysis of the available hydro-meteorological data collected by the project, was assumed to be - 5.5 °C/km. Precipitation was considered to be uniformly distributed across all elevation bands.

Each elevation band was dealt with separately in the module, and, for each band, precipitation was considered to fall as snow whenever the daily temperature of the band dropped below a threshold temperature, T_{snow} . It was then assumed to melt as the temperature rose above a certain "melt" temperature, T_{melt} , at the constant rate of the degree-day-factor for snow, DDF_{snow} . The values used for these parameters are shown in Table 3.4.

Table 3.4 *Parameters for the snow-pack module*

Parameter	**Value**	**Definition**
T_{snow}	+2.0 °C	Temperature threshold to discriminate between rain and snow
T_{melt}	+1.0 °C	Temperature at which snow will begin to melt
DDF_{snow}	4 mm/°C/day	Degree-day-factor for snow, the volume of snow-melt in mm water equivalence per positive degree-day

The snow-pack module conceptualizes the snow storage as a "dry" and "wet" store. New snow onto the snow-pack is added to the dry store. The wet store receives water directly as rainfall and as melt from the dry store, if the daily temperature is above T_{melt}. Water is released from the wet store at a rate proportional to the volume of melted snow. The melt-water then contributes to the PDM rainfall-runoff model that is applied to each elevation band. Where the dry-snow store in any elevation band is depleted, the rainfall contributes directly as input to the rainfall-runoff model in that band.

3.4.3 The Regional Glacier-melt Model

The vast majority of glacier–melt models previously developed have been applied and calibrated on single glaciers only. With an estimated 10,000 glaciers, or more, in the Himalayas, it would be impossible to model each one individually. The regional glacier-melt model developed in this project is the first to attempt to represent both the melt-water contribution from all glaciers in the region and their deglaciation. The model is based on the concept of a generic representation of glaciers by Macdonald and Collins (2002), and considers all glaciers contributing runoff to any individual 20 km cell as a single "generic glacier". The generic glacier of each cell is ascribed an idealised shape and depth, based on the minimum elevation, maximum elevation and area of its contributing glaciers, and the model then calculates the daily melt-water contribution from the glacier and its rate of retreat.

The spatial distribution and areal extent of the Himalayan glaciers was obtained from the Digital Chart of the World (DCW), (ESRI, 1993). All glaciers defined by the DCW were abstracted as polygons in ArcGIS and overlaid onto the HYDRO1k DEM (USGS, 2001) to determine their minimum and maximum elevations and area. Every individual glacier was then associated to the respective 20 km x 20km cell within which the minimum elevation occurred. If more than one glacier had its minimum in the same 20 km cell, then the "generic glacier" of the cell was defined by the lowest minimum elevation, the highest maximum elevation and the total area of all contributing glaciers. The approach is illustrated with reference to Figure 3.6, where the generic glacier for the central 20 km cell is defined by glaciers A_1 and A_2, both of which have their minimum elevations in the same cell, but excludes glacier A_3, which has its minimum elevation in an adjacent cell. Each generic glacier was subdivided into 20 elevation bands (glacier bands), and the area and depth of ice in each band was defined according to a "typical" shape profile, as shown in Figure 3.7.

As with the Snow-pack Module, daily precipitation and temperature were used as inputs to the glacier-melt model. The mean daily temperature in each glacier band was calculated from the mean temperature of the cell, using the same temperature lapse rate model as before (*Equation 3.2*). The partitioning of rain and snow was also determined according to the same temperature threshold, T_{snow}.

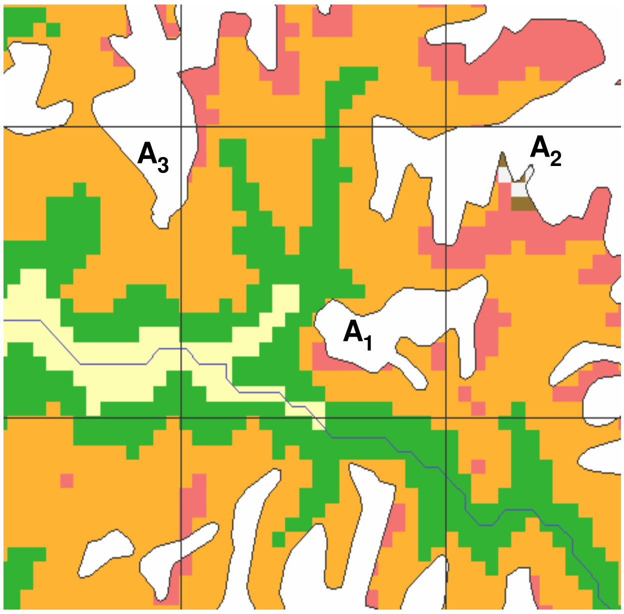

Figure 3.6 *Determining the areal extent of the generic glacier*

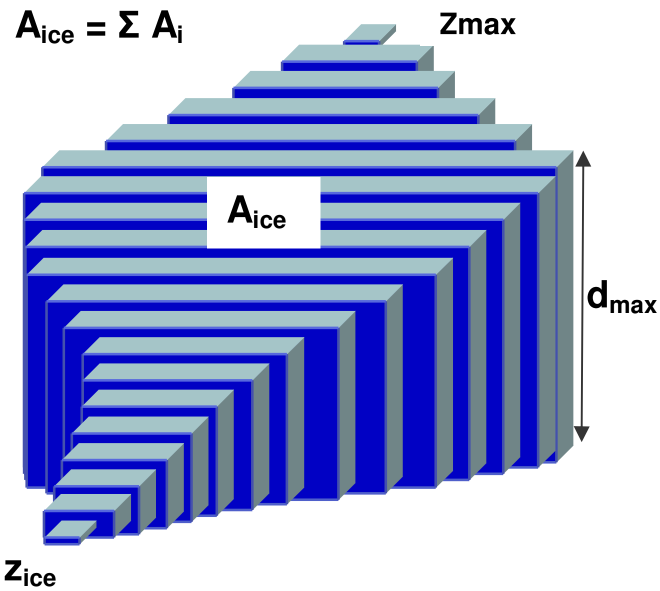

Figure 3.7 *A three-dimensional view of the generic glacier*

The build-up of the snow on the glacier, and the snow-melt from it, was modelled using the Snow-pack Module. At the end of each hydrological year, any dry snow remaining in a glacier band was redefined as "firn" and the dry snow store in the snow-pack module is re-set to zero. Any firn remaining from the previous year was re-distributed evenly as ice between all remaining glacier bands at the end of a year.

Ice-melt (ablation) only occurred from a glacier band when the dry snow store and firn had been exhausted. The daily ice-melt, in mm water equivalence, was also calculated using a temperature index approach, with a value of 8 mm/°C/day used as the degree-day-factor for the ice. The ice-melt from a glacier band, plus rainfall, was then routed through a linear ice-melt store. Innovatively, the retreat, or deglaciaton, of the generic glacier was monitored within the model by recording the daily changes in the ice-depth in each band. Once the ice-depth of a band had depleted to zero, subsequent daily rainfall in the band was added directly to the glacier runoff, inferring an impermeable surface (bare rock) had been exposed.

The volume, V (m^3), of glacier runoff was thus calculated at the daily time-step as the total volume of water released daily from all, snow-, firn-, ice- and rock-covered glacier bands ($i = 1, 2 \ldots n$):

$$V = \sum_{i=1}^{n} A_i \cdot Q_i \cdot 1000 \qquad \ldots(3.3)$$

where A_i is the area (km^2) of band i, and Q_i is the runoff from the band (mm). The daily runoff from the glacier was expressed as a uniform depth of runoff, in mm, over the 400 km^2 area of the 20 km cell.

3.5 Model appplication

3.5.1 Baseline Scenario

The regional model was first applied using the CRU 1961-90 baseline climatology (precipitation, rain-days, temperature and PE) for a 30-year model run at the daily time-step. The resulting daily runoff values for each cell were aggregated at run-time to give estimates of mean monthly, seasonal and annual runoff for each cell in each basin of the study area. Summer runoff was defined as the average total runoff for the months April to September; winter runoff the average total runoff from October to March. These results were taken as the “control”, or “baseline”, for comparison with subsequent scenarios.

3.5.2 Climate change scenarios

A representation of the future climate is necessary to model deglaciation and its effect on the water resources of the Himalayas. Two types of climate change scenarios were considered in this project: incremental scenarios and climate model-based scenarios.

The model was applied with four incremental scenarios of increasing temperature, two incremental scenarios of increasing temperature with increasing precipitation, two incremental scenarios of increasing temperature but decreasing precipitation and one climate-model based scenario, based on output from the UK's Hadley Centre HadRM2 Regional Climate Model, which describes a future climate for the South Asia region for the period 2041 to 2060 (Hassell & Jones, 1998). The scenarios are listed in Table 3.5 below.

Table 3.5 *Climate-change scenarios used in SAGARMATHA*

Scenario code	Annual Incremental change		Basis of scenario
	T (°C/yr)	P (%/yr)	
CTL	0	0	CRU baseline applied, with no incremental changes in P or T
T03	+0.03	0	Average global warming predicted by IPCC (2001a & b)
T06	+0.06	0	Observed warming from temperature gauges in Nepal
T10	+0.10	0	Observed warming from highest 15 gauges in Nepal
T15	+0.15	0	Extreme "hypothetical" scenario
PHM	+0.06	+0.2	High precipitation scenario for South Asia, after Giorgi & Francisco (2000) in IPCC (2001a), with medium and high temperature scenarios.
PHH	+0.15	+0.2	
PLM	+0.06	-0.2	Low precipitation scenario for South Asia, with medium and high temperature scenarios.
PLH	+0.15	-0.2	
RCM	Spatially variable		Derived from HadRM2 RCM (Hassell & Jones, 1998)

The incremental scenarios were applied uniformly to all cells in each respective basin at a daily time-step for a period of 100 years from a nominal start date of 1991. The increments were added, or subtracted, annually to the relevant monthly baseline variable. Outputs were presented as decadal averages of annual and seasonal (winter and summer) runoff.

For the "RCM" scenario, inconsistencies between the CRU baseline data and the HadRM2 data, meant that the HadRM2 data had to be pre-processed to determine the average forecast change (Δ) in monthly precipitation, temperature and PE for every 20 km cell in the study area (see Figure 3.8). These values were assigned to the mid-point of the 2041 to 2060 period. An annual increment was then calculated for each of the 3 climate variables (P, T & PE) in a cell, corresponding to the annual increase, or decrease, of the variable between 1991 (the end of the period covered by the CRU baseline data) and 2050 (the mid-point of the RCM data) (i.e. Δ/60). The regional model was then run for 70-years, representing the period 1991 to 2060, with the appropriate annual increment applied each year to the 3 climate variables in each cell. This dynamic representation of climate between the end of baseline period (1991) and the start of the RCM period (2041) was another innovative aspect of the project, and was necessary in order to describe the evolution of glaciers during this time.

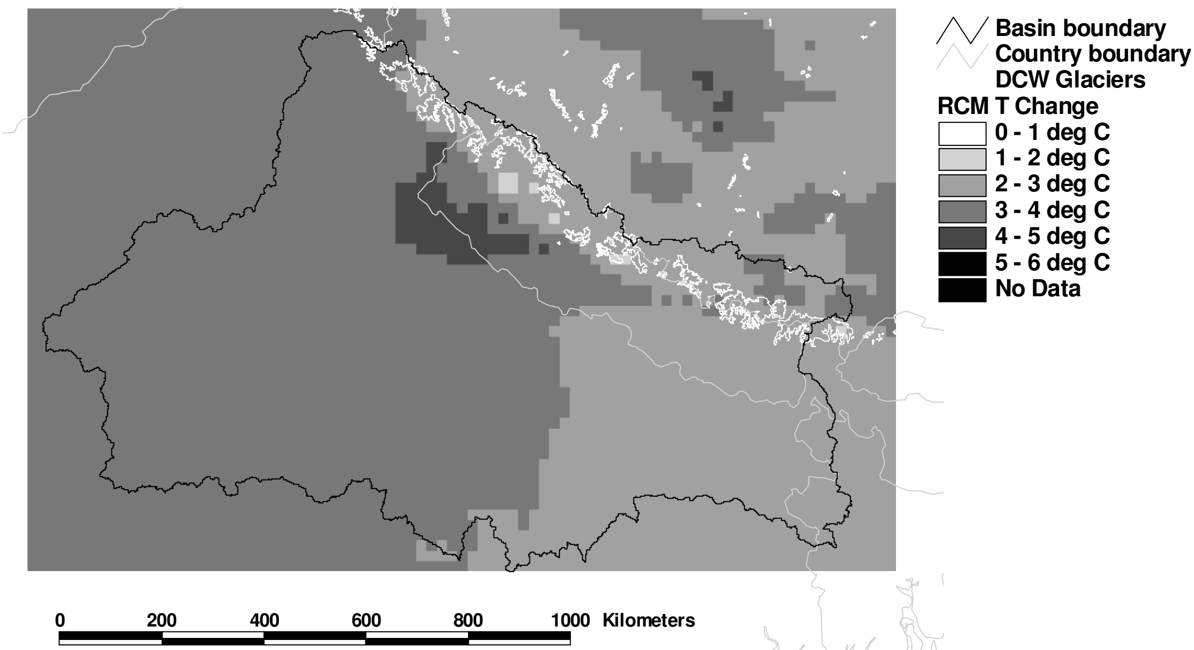

Figure 3.8 *Change in average annual T for 2041- 2060 from HadRM2 (Ganges)*

3.6 Processing of Results

To assess the impact of deglaciation on the water resources of the Himalayas, the outputs from the regional hydrological model, representing the areal distribution of runoff at a 20 km x 20 km grid resolution, were converted into river flows. Comparisons were then made between baseline flows and those from the various scenarios to analyse how the surface water resource availability of rivers may be affected by climate change.

The 20 km grid estimates of decadal runoff (annual and seasonal) for each climate change scenario were imported as grids into ArcGIS and re-sampled to the same 1km x 1km resolution of the USGS HYDRO1k DEM (USGS, 2001). Flow-accumulation grids were then derived, using the flow-direction grid of HYDRO1k (a derivative of the DEM). The accumulated runoff of every cell, expressed in mm, was then converted to units of flow (m^3/s) to produce a grid of annual or seasonal flow, as shown in Figure 3.9. Decadal average annual and seasonal flow estimates could thus be obtained for any of the scenarios, at any location, on any stream or river in each of the three basins.

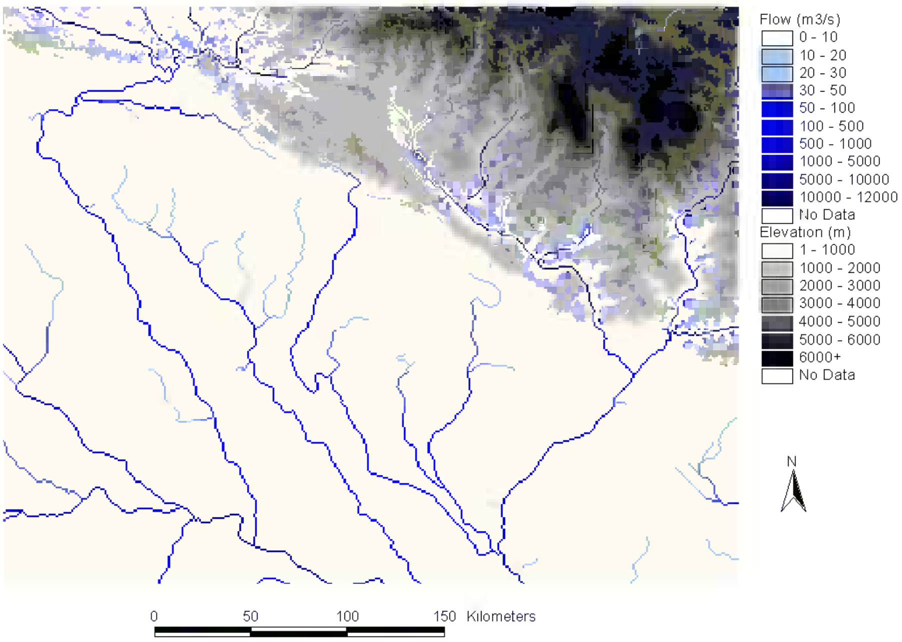

***Figure 3.9** Mean flow in the Ganges basin, derived from output of the regional hydrological model and the HYDRO1k flow-direction grid*

A comparison of baseline mean flow estimates with observed flow data at randomly selected gauging stations reveals that the regional hydrological model provides a reasonable approximation, albeit with a general tendency to underestimate the actual flows (see Table 3.6). As would be expected, variability of results appears greatest in smaller catchments. With the intended next step of expressing the deglaciation impacts in relative terms (% change), it is considered that these apparent errors would be negated, because the same errors would be propagated to a similar extent in the forecasted flows. Thus, the regional hydrological model may be considered a good basis for establishing the potential impacts of climate-change induced deglaciation on the surface water resources of the Himalaya.

Table 3.6 *Comparison of modelled and observed mean flow*

Gauging Station	**Mean flow (m3/s)**		**Bias Error (%)**[1]
	Modelled	**Observed**	
Ganges at Farakka	9850	12293	-19.9
Ganges at Hardinge Bridge	11091	11146	-0.5
Hunza at Danyore	356	366	-2.7
Indus at Partab Bridge	1590	1770	-10.2
Indus at Besham Qila	1653	2450	-32.5
Indus at Kotri	3874	2626	47.5
Chenab at Akhnoor	268	788	-66.0
Arun at Turkghat	437	415	5.3
Sun Kosi at Kumpughat	408	767	-46.8
Tamur at Mulghat	245	337	-27.3

[1]*Bias Error (%) = 100% x (Predicted – Observed)/Observed*

3.7 Impacts on future water resources

Having derived 1 km grid maps of average decadal flows for every scenario in each basin, a comparison of how flows would vary from decade to decade, relative to the baseline, was achieved by overlaying, in ArcGIS, the decadal grids onto the relevant baseline grid. Cell values in the resulting "comparison" grids express the change in flow as a percentage (%) of the baseline. The deglaciation impacts were assessed at 21 specific locations (Table 3.7) in the four "focus-areas" (Figure 3.10) in the Upper Indus, Ganges and Brahmaputra basins. Figures 3.11 through to 3.17 illustrate some of the results obtained; more can be seen in Volume 2.

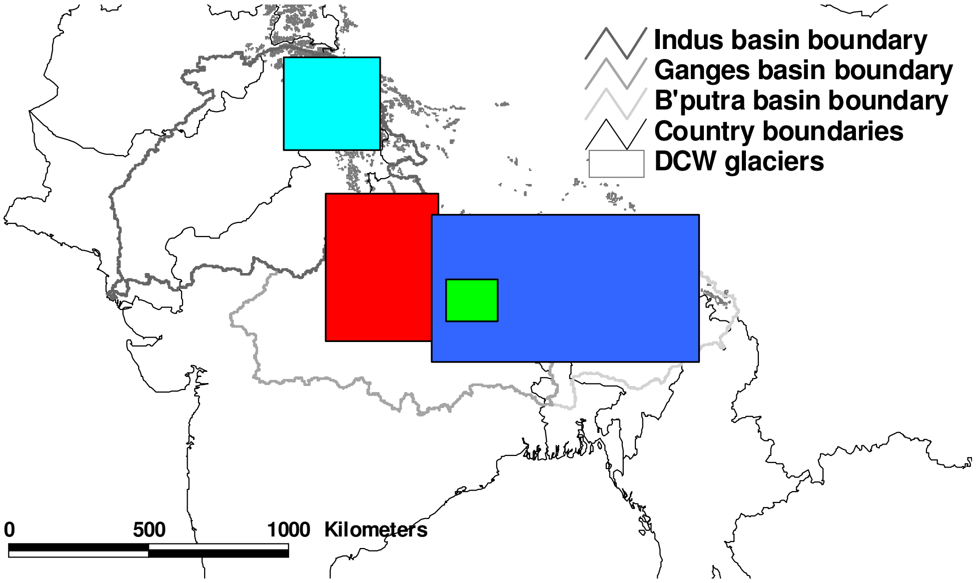

Figure 3.10 *Focus-areas for the SAGARMATHA project: Upper Indus (cyan); River Ganges (red); Kaligandaki (green); Brahmaputra (blue)*

Table 3.7 *Study sites of focus-areas*

Site name	Catchment area (km²)	% glaciation	Model baseline mean flow (m³/s)	
			Annual	Winter
Upper Indus				
Gilgit at Gilgit	14138	11.7	172	39
Hunza at Danyore	27996	25.2	356	64
Indus at Partab Bridge	167982	16.0	1591	248
Indus at Skardu	127099	13.1	1077	162
Shyok at Shyok	38312	16.2	333	36
Indus at Besham Qila	187118	14.6	1702	300
Ganges				
Ganges at Uttarkashi	4524	23.4	85	25
Ganges at Haridwar	23191	16.1	338	108
Ganges at Kanpur	89878	4.2	749	345
Ganges at Allahbad	424937	0.9	2900	1444
Kaligandaki				
Modi Khola at Kusma	642	16.5	14	7
Kaligandaki at Seti Beni	7104	9.3	82	43
Kaligandaki at Katagon	12235	5.4	214	117
Narayani at Devghat	32137	9.7	570	292
Brahmaputra				
D' Zangpo at Samsang	3784	3.0	22	12
D' Zangpo at Xungru	33600	1.9	293	149
Y' Zangpo at Xigaze	103612	0.8	1093	591
Nyang Quu at Gyongze	10960	0.8	184	97
Wong Chhu at Thimpu	748	0.9	17	8
Trongsa Chhu at Zhengang	2755	5.2	161	55
B'putra at Singing	229323	2.1	2077	1114

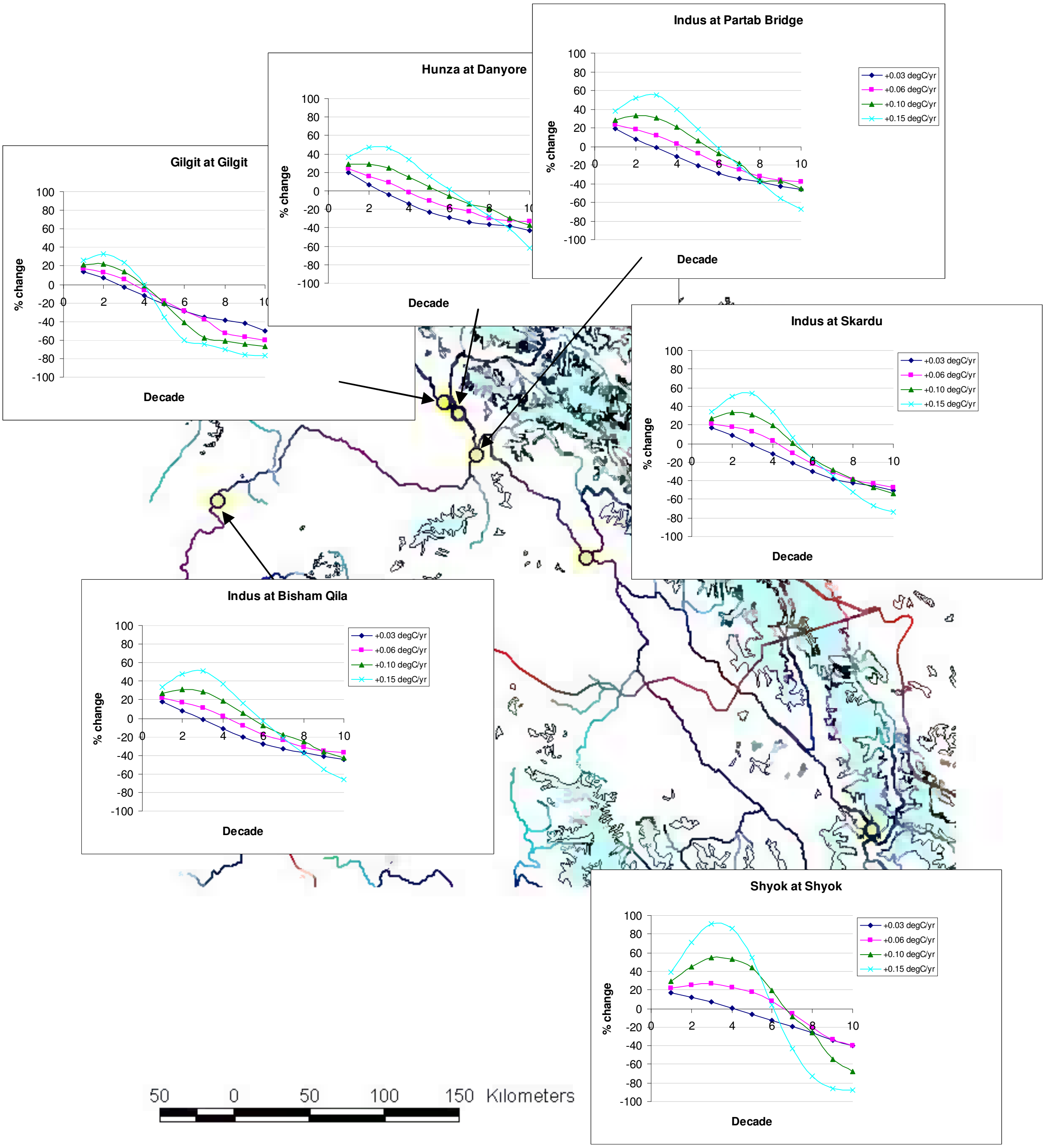

Figure 3.11 *Decadal variation in mean flow (Upper Indus): all T scenarios (T= +0.03, +0.06, +0.10, +0.15°C/yr)*

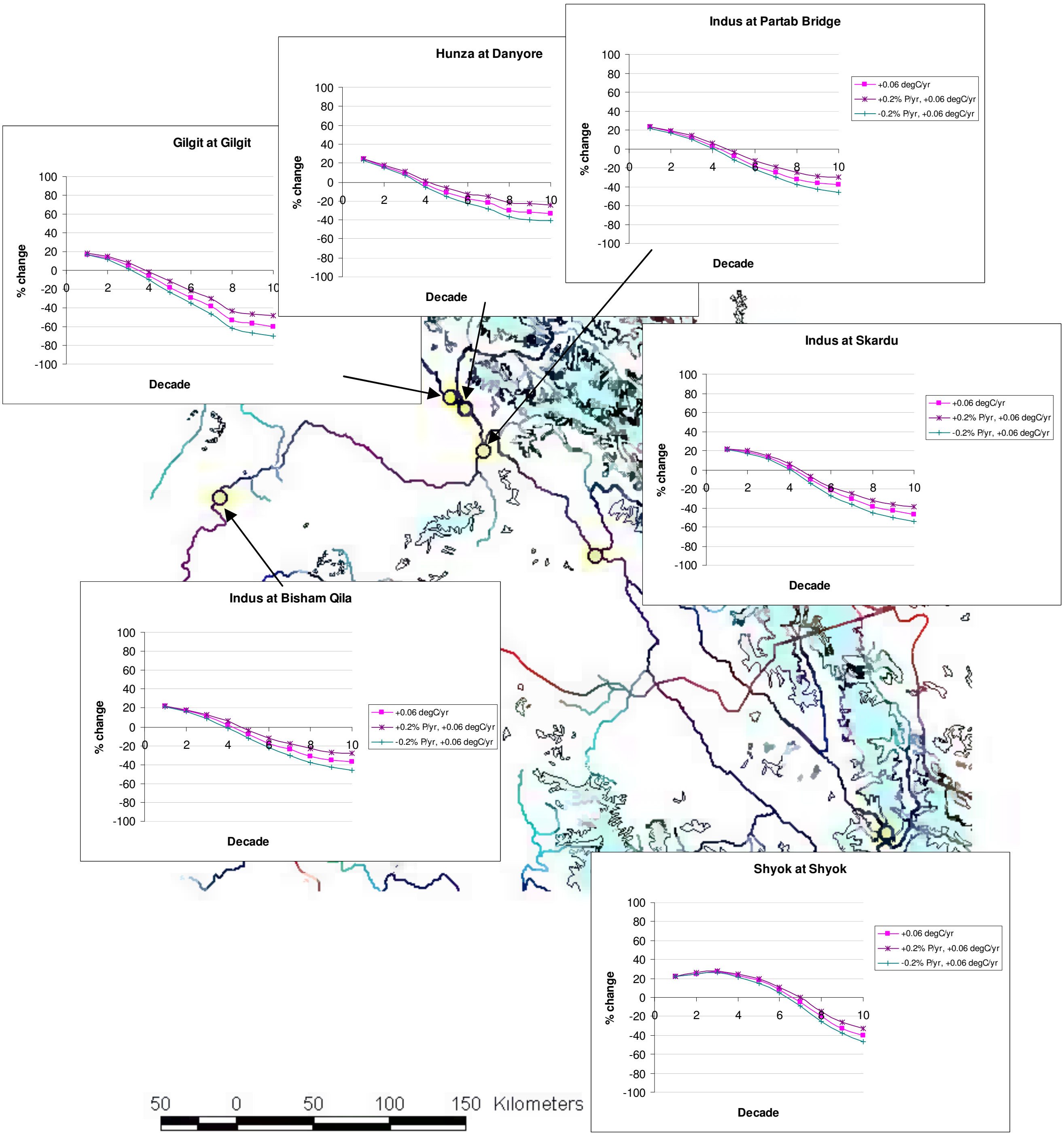

Figure 3.12 *Decadal variation in mean flow (Upper Indus): P and T scenarios combined (P = ±20% over 100 yrs; T = +0.06°C/yr)*

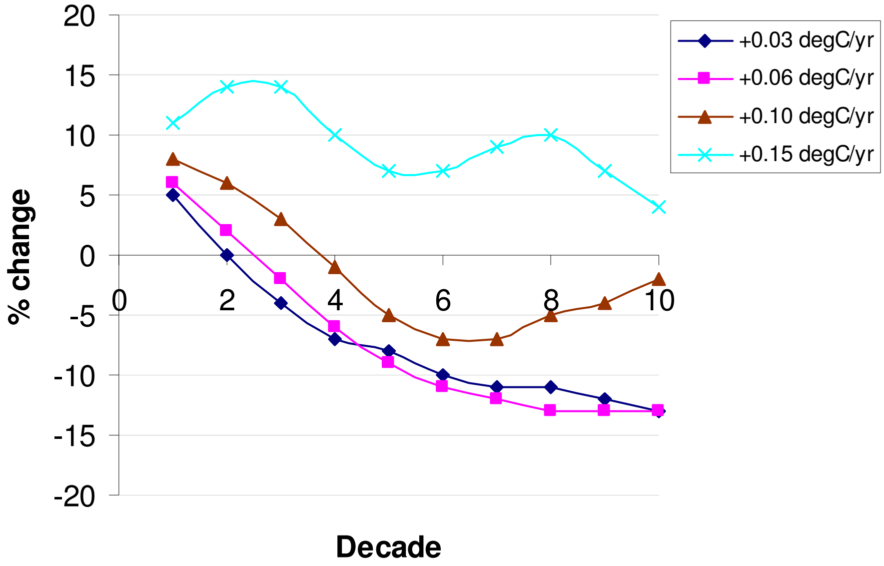

Figure 3.13 *Decadal variation in mean winter flow (Indus at Partab Bridge): all T scenarios*

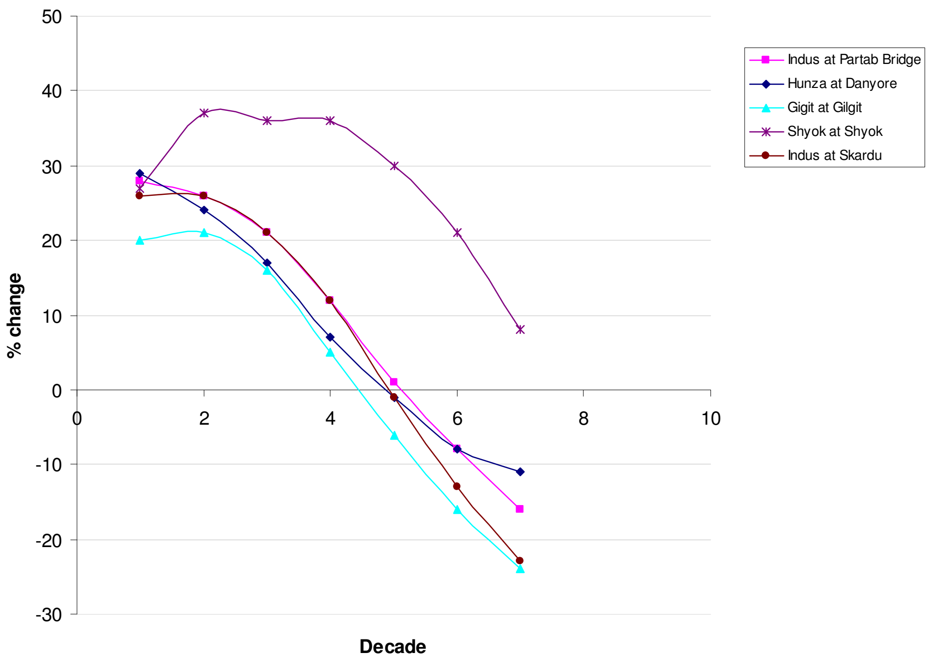

Figure 3.14 *Decadal variation in mean flow, all selected locations (Upper Indus): RCM scenario*

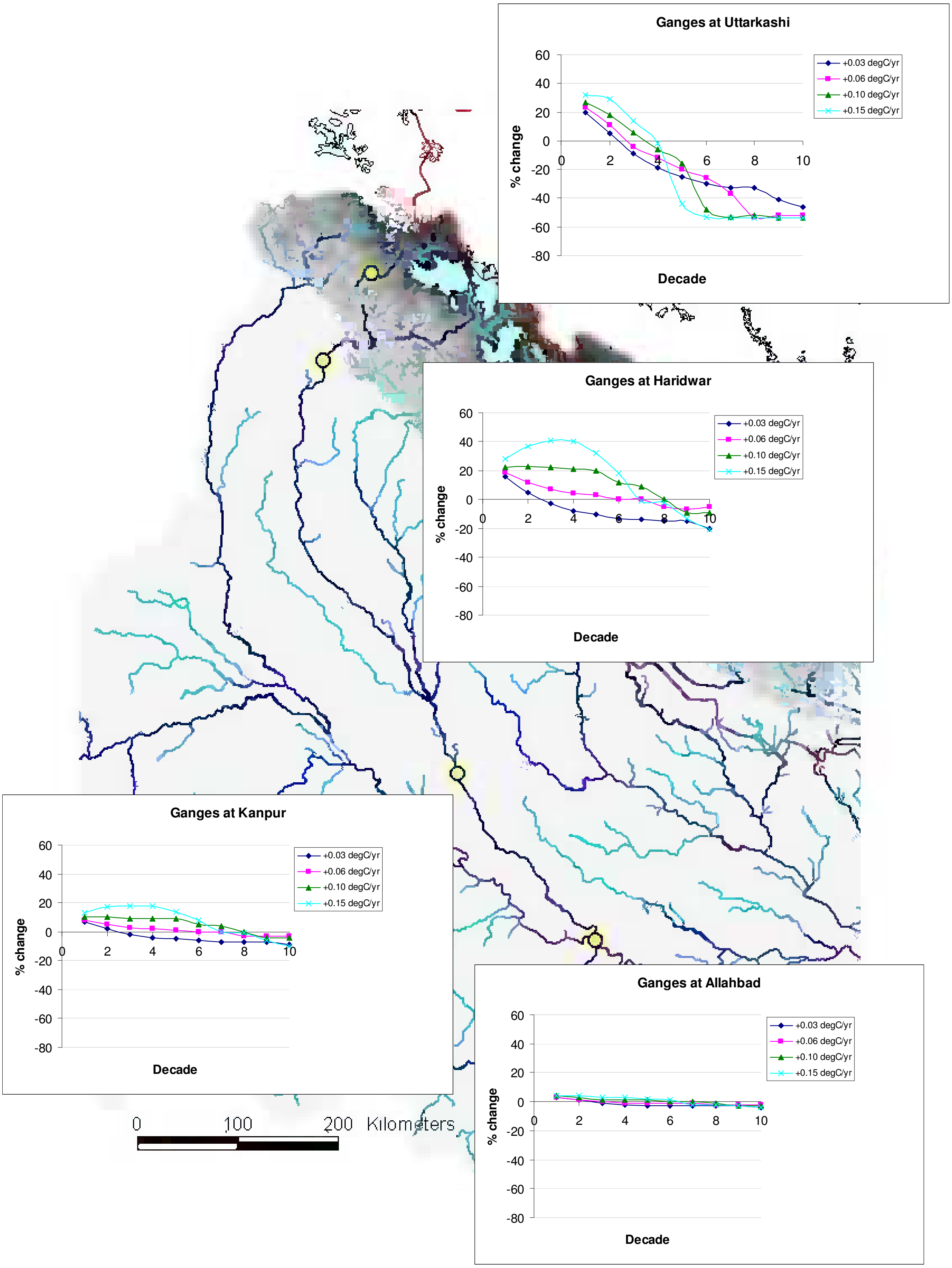

Figure 3.15 *Decadal variation in mean flow (River Ganges): all T scenarios (T = +0.03, +0.06, +0.10, +0.15°C/yr)*

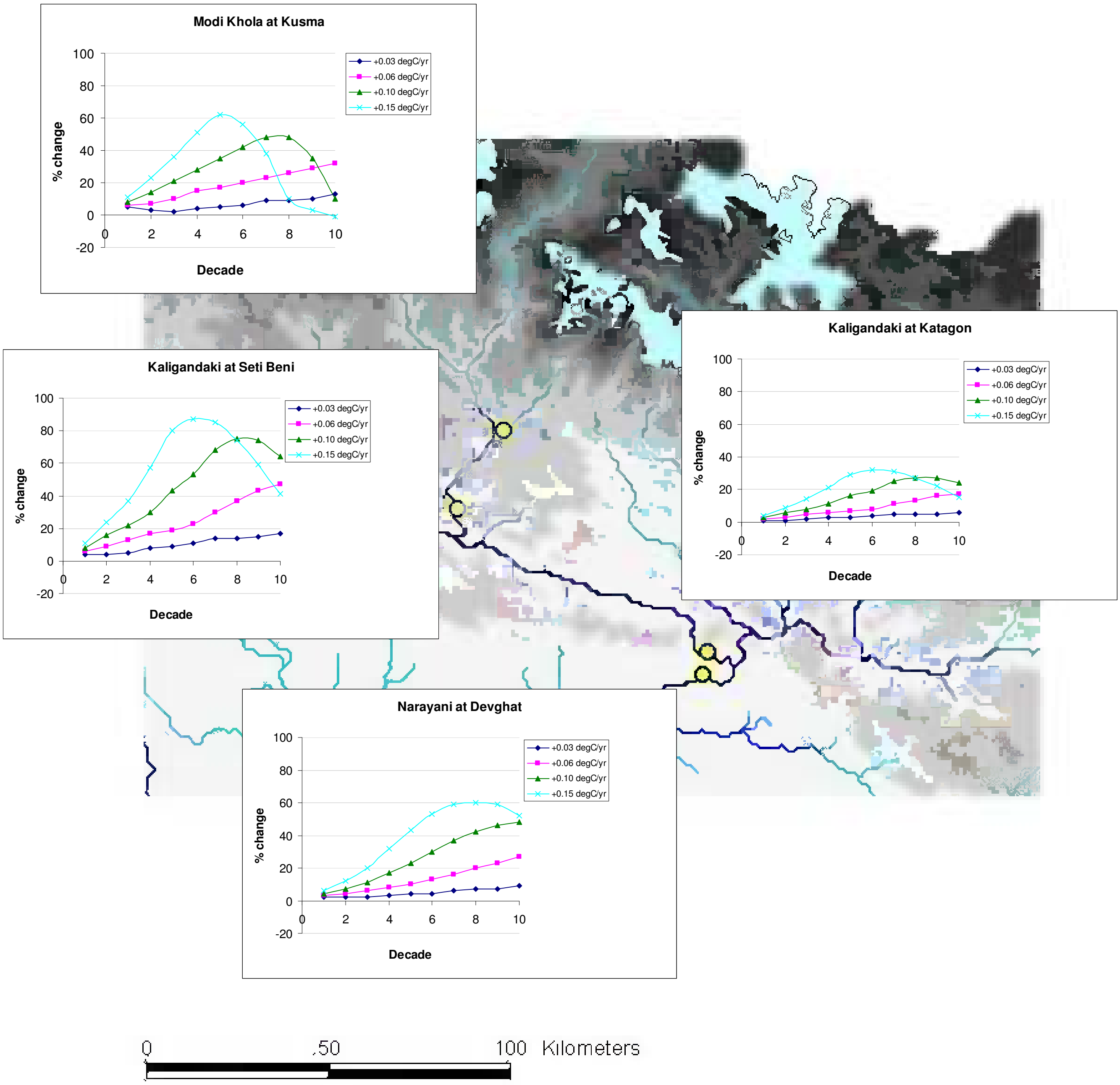

__Figure 3.16__ Decadal variation in mean flow (Modi Khola, Kaligandaki, Narayani rivers): all T scenarios (T = +0.03, +0.06, +0.10, +0.15°C/yr)

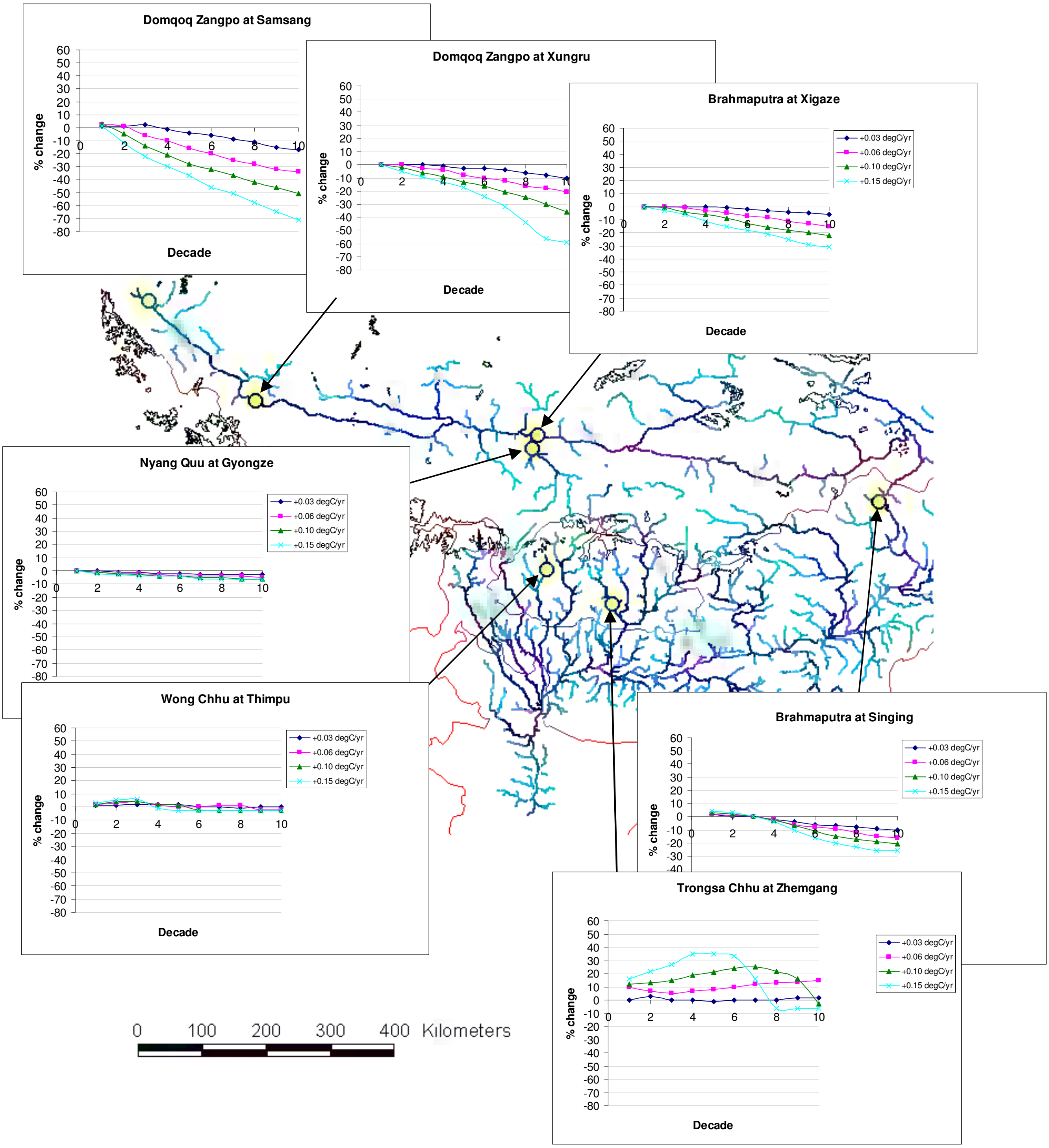

Figure 3.17 Decadal variation in mean flow (Brahmaputra River): all T scenarios (T = +0.03, +0.06, +0.10, +0.15°C/yr)

3.8 Analysis of results

3.8.1 Observations

Inspection of the model results showed that the variation in decadal average summer flow closely resembled that of the (decadal) mean flow and, consequently, the analysis presented here primarily considers the variation in the mean flow only. The results show distinct differences in the potential impacts of deglaciation both regionally, in an east-west direction along the Himalayan arc, and within catchments. In the Upper Indus, the study sites show initial increases of between +14% and +90% in mean flows (compared to the baseline) over the first few decades of the 100-year incremental scenario runs, which are generally followed by flows decreasing to between -30% and -90% of baseline by decade 10 (Figure 3.11). This contrasts with the apparent behaviour in the Kaligandaki basin in the east of the region (Figure 3.16), where decadal mean flows increase for all scenarios, with the most extreme temperature scenarios attaining a peak mean flow of between +30% and +90% of baseline some 5 decades, or more, into the 100-year model run. For the Ganges (Figure 3.15), the response of the river, near the headwaters in Uttarkashi is significantly different from what is seen downstream at Allahbad. At Uttarkashi, flows peak at between +20% and +33% of baseline within the first two decades and then recede to around -50% of baseline by decade 6; further downstream the deglaciation impacts are barely noticeable. In the headwaters of the Brahmaputra (Figure 3.17), there is a general decrease in decadal mean flows for all temperature scenarios; glaciers are few in this area and flows, as expected, recede as the permanent snow cover reduces with increasing temperatures.

The results for the RCM-based scenarios (Figure 3.14) tend to follow those obtained from the more conservative incremental scenarios (e.g. +0.03 or +0.06 °C/yr), albeit with precipitation changes having greater influence, as the proportion of glacier area within catchments decreases. Such results are not unexpected, given that the proportional changes of the RCM scenario generally fall within the range of the more conservative incremental scenarios used.

Variations in winter flow were found to be similar to the mean flow behaviour, even though the relative changes are less. Winter flows of the Indus at Partab Bridge

(Figure 3.13), for instance, peak at between +5% and +10% of the baseline winter flow in the first decade and then reduce to around -13% by decade 10, according to both the +0.03 and +0.06 °C/year incremental temperature scenarios. For the Modi Khola at Kusma, decadal mean winter flows appeared to increase gradually throughout the 100-year model run (as they did for mean flows), to a maximum of over +10% versus the baseline winter flow by decade 10, with the +0.06 °C/year scenario. While the relative changes are less in winter, variations in water availability during this traditionally dry period could have serious implications for water users.

3.8.2 Physical explanation of results

Precipitation appears to have a major influence on how the deglaciation impacts vary regionally. Proportionately, the melt-water contribution to the river flows in a glaciated catchment increases from east to west, as a result of the generally weakening monsoonal influence in the same direction (Dreyer *et al.*, 1982). The relative contribution of melt-water also varies considerably within catchments, diminishing progressively downstream, with increasing rainfall contribution to runoff. In areas of high rainfall, the relative contribution of snow and ice-melt is quickly overtaken downstream by runoff derived from rainfall over the non-glaciated part of the catchment (e.g. Figure 3.15); whereas, in catchments of low rainfall, the melt-water contribution to runoff continues to be a large proportion of the total runoff for some distance downstream (Figure 3.11).

Precipitation also appears to play an important role in insulating glaciers from melting. Glaciers in the west of the region are exposed to melting earlier and for longer, because of the limited precipitation they receive. They will tend to lose mass more rapidly and be more susceptible to deglaciation. However, in areas of high annual precipitation, such as in the eastern Himalayas, the glaciers are protected by a perennial covering of snow, until the snow has melted. Dense cloud cover during the monsoon provides further protection during the time of year when the melting processes (e.g. radiation) are most intense. A strong and intense monsoon would, therefore, protect glaciers from melting, with the consequential reduction in ice-melt compensated for by the increase in precipitation. Conversely, in the event of a weak monsoon, the reduced snow cover would cause an increase in ice-melt, and mass would be lost rapidly from the glacier, resulting in retreat.

The volume of snow and ice that is available for melting also has a bearing on how rapidly the impacts of deglaciation (i.e. the initial increase in flow, time to peak and the subsequent recession of flow) are felt in catchments. Where snow and ice are in abundance, the time taken for flows to peak and then recede is delayed considerably, such as in the Kaligandaki basin (Figure 3.16), which has the Annapurna massif in its headwater. Where the ice-store is limited, flows would be expected to quickly attain their peak and diminish. Such behaviour is seen in the results for the Ganges at Uttarkashi (Figure 3.14), although this may be more an artefact of the model than what might occur in reality (see Section 3.8.3).

3.8.3 Limitations of the model

Of course, the results presented here are largely predicated on the design of the model and the input data used. For instance, there is a concern that the CRU data, which is based mainly on observations at low to medium elevations, underestimates precipitation and overestimates temperatures at high elevations. This may help to explain the apparent underestimation of flows shown in Table 3.6.

The representation of the glacier ice in the model will also have affected results. The project used the Digital Chart of the World because it was the best dataset available that defined the permanent snow and ice cover consistently for the whole study area. However, it may not necessarily have been an accurate representation of the initial glacier cover area everywhere. The future development of the regional model could seek to apply new remote-sensing based datasets (e.g. ICIMOD, 2001 *a&b*) to determine a more accurate representation of the initial areal extent of Himalayan glaciers. As well as the input data, the values that are assigned to model parameters influence the results. For example, the model results appear sensitive to the assumed depth and area of the generic glaciers: further research is needed to establish optimal values for these parameters and others used in the model.

3.9 Conclusions

Despite the limitations of the model, the plausibility of the results obtained means that the following conclusions can justifiably be made:

- the widespread catastrophic water shortages forecast by some experts are unlikely to happen for many decades, if at all;
- some areas may even benefit from increased water availability for the foreseeable future ;
- the threat, that all of the region's glaciers will soon disappear is ill-founded;
- rivers where glaciers contribute significantly to runoff are most vulnerable to the impacts of deglaciation;
- in certain areas, such as in the Upper Indus and Upper Ganges, deglaciation may, indeed, cause a significant reduction of river flows over the next few decades;
- deglaciation would have potentially serious consequences for water availability in these areas, and measures to mitigate the impacts should be urgently considered.

4. An assessment of the impacts of deglaciation on communities and livelihoods

4.1 Introduction

This chapter summarises the activities and outputs of the "livelihood analysis" work package, and addresses the impacts of climate-induced deglaciation on communities and livelihoods in the Himalayan region. While the hydrological component considered the water resources of the entire Indus, Ganges and Brahmaputra river basins, the livelihood impact study was conducted on a variety of scales: at the community level, in a catchment in central Nepal; at a basin scale, considering activity along the banks of an economically important river in central Nepal; and finally, more generally, at the regional scale. One of the main objectives of the livelihood component of the project was to investigate how downstream communities would be influenced by deglaciation, and what possible adaptation strategies could be developed in response to these impacts. The findings of this research are based on detailed household and community survey and on extensive stakeholder consultation at local, national and international levels. Full details of the activities and results from this component of the project can be found in Volume 3 of this Final Technical Report, with supplemental information provided in the "Background Documents".

4.2 Research Activities

The research activities undertaken within the "livelihood impacts" work package are summarised below, and include descriptions of: the community assessment in the Modi Khola catchment, Nepal; the development of a spatial database and GIS mapping of the catchment; the Modi/Kaligandaki river corridor study; an inventory of water use in the rivers of Nepal; and a series of stakeholder consultation and workshops that were conducted towards the end of the project.

4.2.1 Community Assessment, Modi Khola

In order to establish a base line of understanding about how people live in mountainous catchments, household surveys were carried out in 12 communities across the Modi Khola in Central Nepal (Figure 4.1). These communities were selected on the basis of their geographical location within the catchment. In addition to the household surveys, information was sought through discussions with representative groups and key informants (Figure 4.2) to provide community-level information about resources, livelihood assets, and qualitative information about perceptions of climate change and its relation to local livelihoods.

Figure 4.1 *Modi Khola Study Area*

Figure 4.2 *Community discussions in the Modi Khola*

4.2.2 Development of a spatial database and use of GIS mapping

A spatial database for the Modi Khola catchment was developed with the use of Geographic Information Systems (GIS) technology by digitizing existing hard-copy topographical and political maps and from the georeferencing of primary data from the community survey and an inventory of water use in the area. An inventory of different water uses was made for the whole catchment through observation by team members and in consultation with local people and spatially referenced with the aid of GPS (Global Positioning System) receivers. The water uses recorded include water mills, irrigation canals, power plants, sources of piped water supply and religious and culturally important places. Figure 4.3 shows the Modi Khola catchment and some features including the location of domestic water sources, micro-hydro generation sites and the study settlements. The creation of this integrated digital database provides a useful set of baseline information from which future work in the area can draw. See Appendix 2 of Volume 3 for more information on to the GIS methods used, and additional examples of mapping from the spatial database.

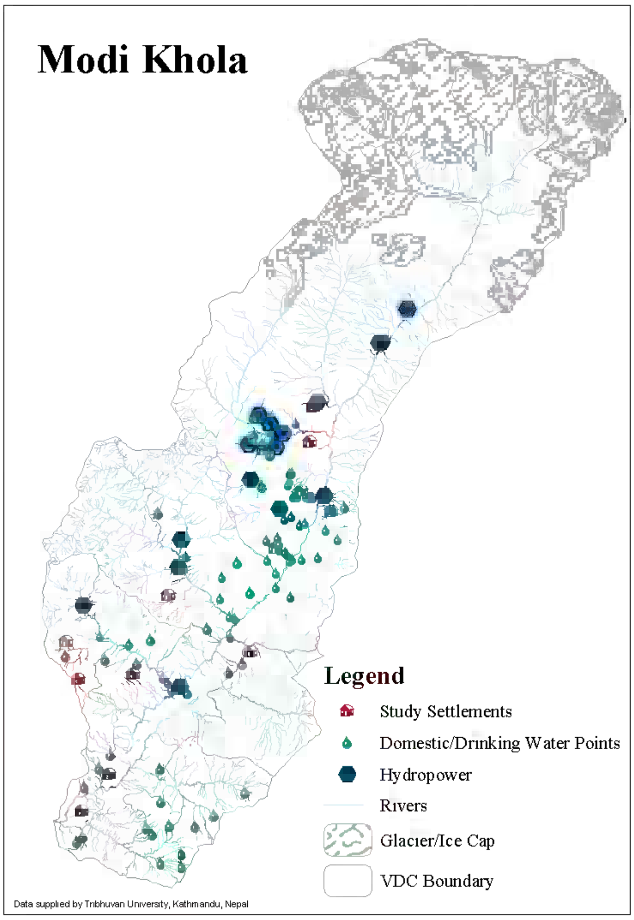

Figure 4.3 *Modi Khola water use examples*

4.2.3 The Modi/Kaligandaki river corridor study

To investigate the potential impacts of deglaciation at a wider scale, a study of the Modi/Kaligandaki river corridor was initiated to examine how livelihoods and economic activities could be impacted by changes in river flows. This basin-scale assessment links to the studies carried out at the community level and was made using data and information collected along the length of the river, from the headwaters of the Modi Khola and along the Kaligandaki river down to the Nepal-India border (Figure 4.4). This area has a population of over 600,000, with larger populations outside the area dependent on its water resources and infrastructure. The study focused on energy supply, agricultural and industrial production, and household consumption of river water.

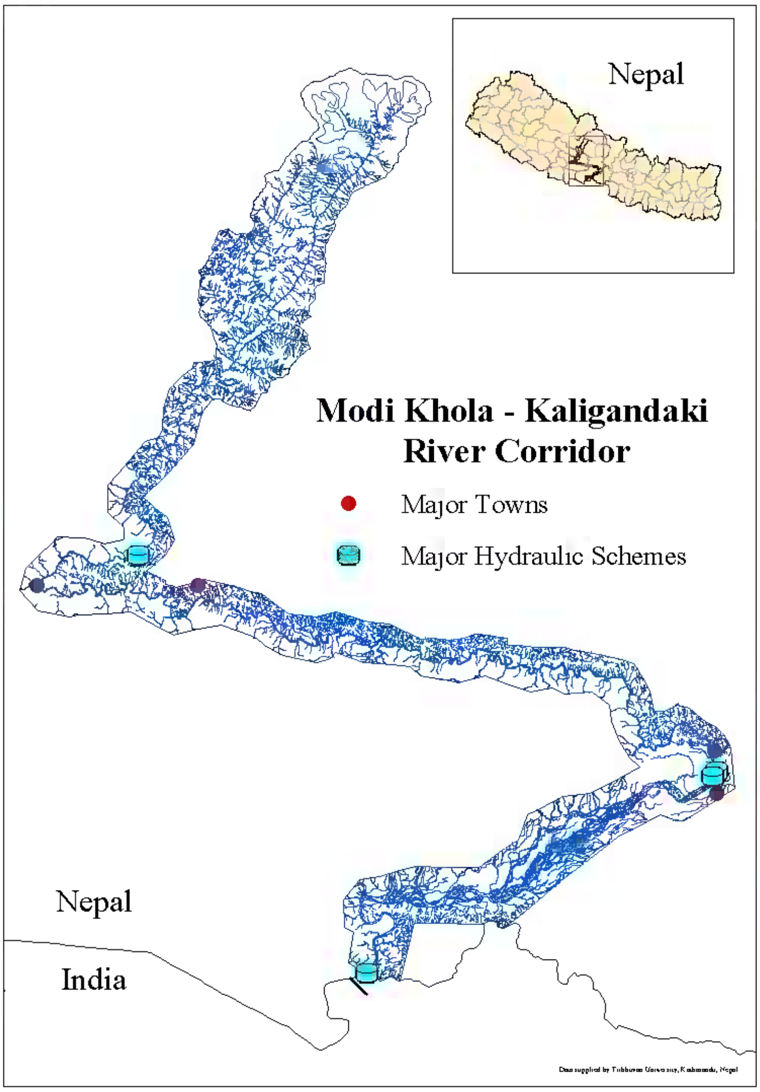

Figure 4.4 *The Modi/Kaligandaki river corridor*

4.2.4 Inventory of water use in the rivers of Nepal

In addition to the detailed water use inventory carried out in the study catchment of Modi Khola, a water use inventory of all other rivers of Nepal was prepared through the collection and review of secondary data and information from several national and international organizations in Nepal. This study includes information on irrigation, hydropower, industrial use, household water supply, fishing, and water transportation across the country. As with all the surveys, many of the datasets collected were spatially referenced and integrated for display and analysis using GIS software. Figure 4.5 shows the status of hydropower development across the country and highlights snow-fed river locations.

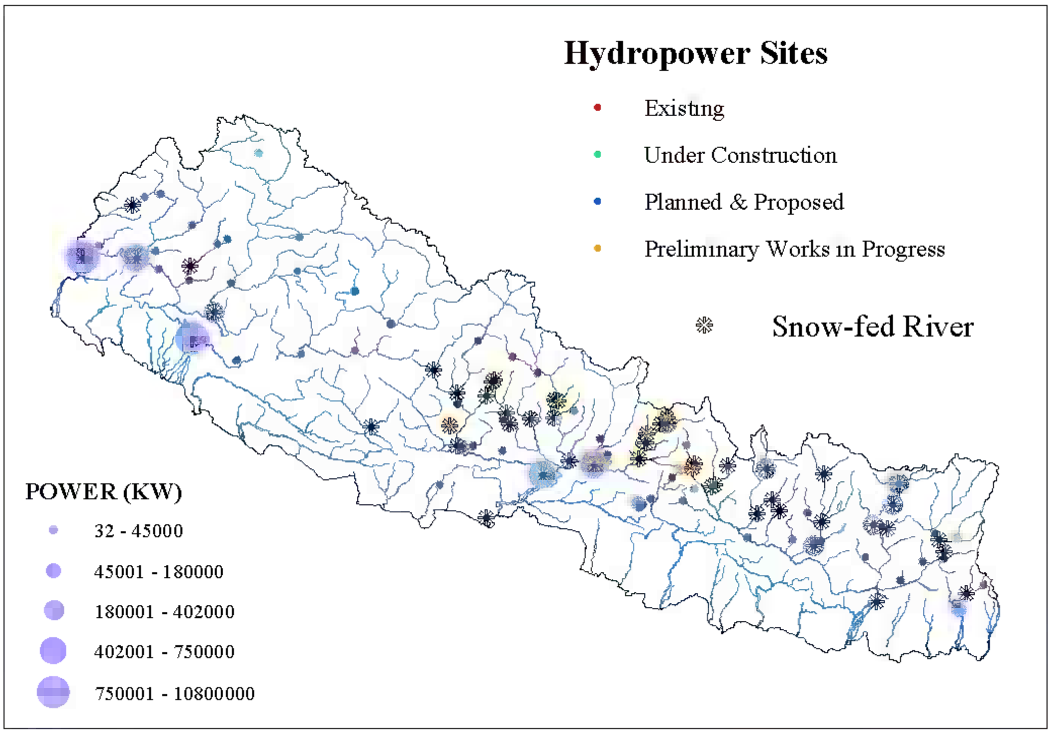

***Figure 4.5** Hydropower development across Nepal*

4.2.5 Stakeholder consultation and workshops

During the course of the SAGARMATHA project, participatory appraisal and consultation has been an important part of the research process, and consultation with communities and stakeholders took place at local, national and regional levels. The major objective of these stakeholder consultations was to gather information, ideas and knowledge from local people, experts, water scientists, and other concerned authorities about how water resource impacts may be felt by different sectors of the economy and different social groups. This approach provided the basis for the development of adaptation strategies to cope with the impacts of climate-induced deglaciation.

Modi Khola workshops: consultation at the local scale

Two stakeholder meetings were conducted in the Modi Khola catchment in March 2004, representing downstream and upstream sub-regions. Participants represented different stakeholder groups including farmers, social workers, technicians, businessmen and tourism representatives. Official representatives from district authorities related to irrigation, drinking water, electricity and alternative energy development also participated.

The Kaligandaki corridor workshop: consultation at the basin scale

A one-day workshop was held in Pokhara, Nepal, on 21 April, 2004, to both provide feedback to relevant stakeholders about the work and findings of the project and to inform the development of potential adaptation strategies. Participants included government officials, academics, water resource managers, hydropower engineers, NGOs, farmers, tourism officials and local political representatives. In the first part of the day project team members gave presentations to deliver the results of the study to the participants. The second part of the workshop provided the opportunity to investigate group perceptions of various adaptation options through ‘breakout’ group sessions followed by plenary feedback. In addition, each participant gave their individual input by completing specifically designed consultation sheets.

The New Delhi workshop: consultation at the HKH regional scale

This two-day workshop in New Delhi, India, on 27- 28 April, 2004, was designed to provide feedback from the project to relevant stakeholders from different countries of the Hindu Kush Himalaya region, and also to the international scientific community. In addition, it was an important opportunity to examine the views of stakeholders concerned with larger scale issues, on the potential impacts of climate change on water resources, and potential adaptation strategies. Participants included government department officials from across the region and representatives of the international research community. Presentations were given by the project team and by representatives from India, Nepal, Bangladesh and Bhutan, providing the opportunity to highlight significant regional variations in potential impacts. Following technical presentations, the second day of the workshop was devoted to discussions of impacts and adaptation strategies with a focus on the themes of food security, commerce and tourism, and hydropower.

4.3 Research Findings

4.3.1 Findings from the household surveys

Approximately 75,000 people live in the Modi Khola with the majority living at altitudes between 1000 and 2000 metres. A total of 360 households were surveyed during the study representing 2,331 people. The Modi Khola catchment is primarily forested with almost 20% of the land under cultivation and over 28% of the area covered by snow and ice or rocky cliffs. Almost half of the population considers agriculture as their primary occupation with 30% in education, reflecting the high proportion of the population who are below 25 years of age. The third major occupation was related as being in services.

As in many countries, subsistence households often have difficulty with the cash flows needed for participation in a modern economy, such as payment for school fees, health costs and footwear, etc.. The percentage of people in a society who are in receipt of a loan of any type represents households whose consumption patterns are likely to outweigh their income streams. It was found that households in the lower zone are much less likely to be in receipt of loans than those in the upper zones, indicating the increased levels of vulnerability and food insecurity faced by communities living at higher altitudes. Another factor that will influence a household's vulnerability to the hydrological impacts of climate change is the availability of more than one source of water. In these communities, it was found that, in general, people use the rivers for domestic use when boreholes and wells run dry.

During the household surveys and discussions, people were asked about their experience and perceptions regarding climate change and variability and the occurrence of extreme events over the last 10 years. The majority of respondents considered that there had been no change in rainfall, temperature or snowline (57.8%) and 68% felt that river flows were unchanged. A decrease in land productivity was observed by 48% of respondents, although 67% felt that water collection distances had decreased, indicating water access had been improved over the period. In all altitude zones, the loss of crops from natural disasters was reported. Those in the lower altitude zones reported damage and loss from drought, hailstones, floods and landslides, while in the high altitude zone hailstone events were by far the most damaging. This suggests that more research should be initiated to investigate potentially robust crop types, or those which would improve under the expected conditions. When considering different future scenarios, very few respondents thought that food shortages would occur but it was clear that both the middle and upper zone inhabitants considered longer and colder winters likely to reduce crop production. Participants also gave their views on changing land cover, biodiversity, and the availability of fodder, fuel-wood and other forest products.

It was concluded that the groups most likely to be vulnerable to climate-induced hydrological variation are those living at higher and middle altitudes. Large numbers of people live in the middle altitudes in the Modi Khola and, if the change in climate is characterised by shorter warmer winters, it may be that increases in crop productivity will be observed. While this suggests an improvement in food security, the impact on farm incomes is uncertain. If, on the other hand, winters are colder and longer crop production is likely to fall. This highlights the uncertainty associated with climate impact research and emphasizes that great care must be taken when interpreting the results.

4.3.2 Findings from the Kaligandaki Corridor Survey

Any changes in hydrological regimes can have serious consequences for infrastructure such as dams, hydropower and irrigation schemes. Currently, there are three hydroelectricity projects situated along the corridor with another three planned. Energy generated by these schemes is not only used locally but also connected to the Nepal national grid and output from the Gandak plant on the India-Nepal border is shared between the two countries. Of the three proposed hydroelectric projects planned for construction, two are located in the headwaters of the Modi Khola area, and are likely to be affected by deglaciation and there is a need to consider the impact of changes in runoff on infrastructure and power generation design. A third, and largest, scheme is planned in the lower part of the corridor where the impact of deglaciation will be less significant but the effect of increased extreme precipitation and floods could be a concern. Two major irrigation projects exist along the Kaligandaki and presently service land farmed by approximately 50,000 households in Nepal and many more in India. Water in the corridor is also used by large industry, especially in the lower part where a pulp and paper plant is located.

In terms of traditional uses of water, water mills *(ghats)* for grinding food grains, particularly paddy, maize, millet and barley, are very important. There are 55 water mills along the Modi River in the upper part of the catchment with over 3000 households directly benefiting from these mills. About half of these are seasonal but the rest operate throughout the year. In addition, many traditional irrigation *kulos* (canals) are in use diverting flow from tributaries and natural springs.

Fishing is another important economic activity along the Kaligandaki river corridor, especially amongst a number of ethnic groups for cash income and diet. Fishing is important not only for subsistence but also for commercial and sports fisheries. The Kaligandaki has a number of fish species specially adapted to extreme gradient and there is concern that irrigation schemes are impacting on their habitat. Water in the region also has important religious and spiritual uses with 22 traditional mills along the river corridor used for bathing and cremation. Changes in runoff, either increases or decreases, may cause inconvenience and increased risks for local people. It is likely that these *ghats* would have to be relocated or reconstructed at high cost to the community. Further, the area is a popular destination for tourism, particularly for white-water rafting. Changes in runoff may affect rafting activities and in turn affect employment and marketing opportunities of local people living along the corridor.

These examples show how the social and physical capital available for a community can be affected as a result of changes in the natural resource base. On the basis of the modelling results it is likely that the upper part of the corridor will be considerably influenced by any change in runoff due to deglaciation with impacts decreasing downstream.

4.3.3 Observations from studies across the HKH region

A review of case studies from river basins across the Hindu Kush Himalaya region highlighted how observed and predicted climate change and variability are impacting populations across the region in economic, social, cultural and environmental terms, providing comparative assessments with the case study in Nepal. A study from the Siran River valley in the humid northwest region of Pakistan showed a general increase in temperatures and precipitation and an increase in the frequency and intensity of the monsoon. The study predicted negative impacts on livestock production in the area due a decrease in suitable pasture although an increase in the forested area is expected. Available water for drinking and irrigation may decrease and the potential for damage to life and property increases as deforestation and inappropriate agricultural practices continue. Studies from the Jhelum River basin in India revealed significant observed climate change, environmental degradation and cultural adaptations with increasing temperatures observed in the Kashmir region over the last 20 years. A general decline in water quantity and quality has been observed in nearby tributaries, springs and lakes. The warming observed in the region is seen to have affected society in areas such as the dressing patterns of people and in building design.

4.3.4 Results and conclusions from stakeholder workshops

The workshops carried out during this project have enabled consultation to take place at a range of spatial scales.

Local workshops: Modi Khola Catchment

The main issues evolved from this set of workshops related to perceptions of climate change and appropriate adaptation strategies. Participants reached a consensus that over the last 10 years temperatures have risen and there has been an increase in the amount and intensity of rainfall and an increase in extreme events, some of which have caused heavy erosion and damage to life and property. Other points of note were observations of the upward shifting of paddy cultivation, the early ripening of crops and the prevalence of mosquitoes in higher altitudes. Participants felt that these changing conditions served as proxy indicators of climate change. The majority considered that higher intensity and untimely rainfall events are having a negative impact on livelihoods, especially farming. It was also considered that increases and decreases in river flow would adversely affect livelihoods. Members of the research team presented some generalised results from the hydrological modelling carried out for the project and local stakeholders suggested a number of adaptation strategies to cope with the predicted changes in water availability. These included:

Changes in cropping pattern, substitution of crop varieties and species

Participants concurred with the results from the community surveys that changes such as localized high intensity rainfall followed by droughts in adjoining areas and changes in the pattern of hailstorms and snowfall badly affect winter crops such as wheat, barley and potato, particularly in the upstream area. They recommended that the introduction of new varieties of crops suited to the changing weather pattern should be explored and gave examples of suitable alternatives.

Changes in animal husbandry techniques

The contribution of livestock to the local economy is significant but livestock numbers have declined due to the expansion of forest land, the restriction of grazing in conservation areas, out-migration and new economic opportunities. Despite this, the demand for livestock products such as milk and meat is increasing and the decline in manure availability is affecting crop productivity. The promotion of livestock farming of improved varieties was recommended to meet local demand and to provide employment generation and extra income.

Promotion of social networks

Social networks greatly help local people in difficult situations and the existing social networks are not adequate to cover environmental issues. There is a need to increase awareness of local people regarding global climate change and its associated impacts.

Development of early warning systems

There was a call for the development of early warning systems to protect communities in these areas from extreme flood events and increasing threats to life and property.

Development of fishponds and fish breeding

People in this discussion observed that the fish population in the Modi Khola has declined sharply, possibly due to recent road and dam construction. Although not directly attributed to climate change it was suggested that the development of fishponds and the introduction of new varieties of fish could greatly help in restoring fishing and related activities for the community.

Promotion of cultural tourism

The contribution of tourism to the household economy is significant in the upstream region of the Modi Khola catchment. The establishment of a natural history and cultural museum would be beneficial in promoting tourism activities in this region.

Migration

The contribution of remittances to household income from those migrating out of the area is significant. It was considered important that any disruption to these could cause severe poverty in some households.

Changes and modification in design of water-related infrastructure

The design specification of infrastructure such as water mills and micro-hydro plants could be modified. Improvement in the design of traditional mills (wooden chute with wooden blade) would increase processing capacity. Rainwater harvesting and the development of alternative energy systems should be encouraged.

Development of equitable management strategies

It was suggested that a priority list of water uses should be prepared and legal provision for water use should strictly be followed to avoid conflicts over water use. As suggested by local stakeholders, mutual understanding and discussions could solve conflict among water users.

Basin workshop: Kaligandaki Corridor

During the course of the discussion sessions at this workshop, individuals had the opportunity to express their personal views on a number of issues. Over 36% said there was a need for more equitable water allocation, 22% felt that more public awareness should be raised about the possible impacts of climate change on water resources and 20% stated the need for better water and natural resource management.

A number of statements and recommendations came out of the consultation informing the research findings. Poverty, depopulation, unemployment, and the unpredictability of seasons were agreed on as the main problems for mountain communities, with other problems including lack of infrastructure and inappropriate farming practices. Actions regarding improvement of livelihoods should focus on farming, tourism, external remittances, small scale industry and handicrafts, the use of medicinal plants, and the promotion of community forestry and non-timber forest products. Participants were asked to rank a selection of issues for inclusion in policy recommendations. Those considered most important were:

- Build awareness of the impacts of climate change
- More participation in development of climate response policy
- Better monitoring and data collection about upper mountain areas
- Participatory survey on selected indicators of climate change
- Develop mechanisms to support and promote adaptation strategies
- Investigate potential for water saving techniques
- Encourage the development of experimental cropping

Other suggestions included:

- Disseminate research findings among all levels of society, not only policy makers
- Identify geographical locations safe from natural disasters
- Introduce a comprehensive Water Use Act by the government
- Restore forests in upper catchment areas (near glaciers)
- Increase participation of women and marginalized groups
- Increase integration and coordination between government departments, NGOs, etc.
- Implement catchment conservation projects and afforestation programmes
- Promote and foster existing social heritage in tourism development

International workshop: HKH Region

During the workshop in New Delhi, an overview of the current situation relating to deglaciation in selected countries of the HKH region was given. These are summarised below, and provide some insight into how water resources may be impacted by climate change in different parts of the region.

In *India* there are around 5000 glaciers, and some 50% of streamflow in the Himalayan foothills comes from snow and ice. 64% of the total water resources for India come from the three main river systems; Ganges, Brahmaputra and Indus. In these basins the response to climate impacts will be greater near the glaciers, and there appears to be a likelihood of significant increases in runoff under higher temperature conditions. The retreat of the glaciers is likely to give rise to more flooding, but much more site specific information is needed for water resource planning. In contrast to this, in recent years low flows in major river systems have had the effect of reducing the output from hydropower plants by as much as 50% in some cases.

In *Nepal*, there are 3252 glaciers and many have been showing some evidence of retreat, in some cases almost 10m/yr. In general, glacier lakes are growing in size and observed hydro-meteorological and glaciological data tends to support model findings indicating a degree of glacial retreat. In some areas, glacier lakes have become very unstable and the risk of outbursts is high. Some attempts to find a technical solution, including siphoning water from the lakes and attempts to generate power from them, have been tried but with no real success. As a result, investment in the development of early warning systems has begun.

Precipitation is increasing across *Bangladesh* with corresponding increases in runoff. In spite of this, some areas experienced reduced flow rates following the 1977 water sharing treaty due to more upstream abstraction. Across the country, issues include bank erosion, loss of trees and crops, non-potable river water, saline intrusion, water logging of channels, dry season drought and persistent floods. In 1998, 73% of the country was flooded and, in an average year, 22% of the country floods. In 1999, salinity reached a record level, likely to increase in the event of sea-level rise. Drought also affects 25% of the country, and large areas are also subject to arsenic contamination.

In *Bhutan,* glaciers have been the focus of much research. There are 677 glaciers in the country of which 24 have been identified as potentially dangerous. Concern has grown since a large glacial lake outburst flood occurred in 1994. In 1974 and 1981, aerial surveys were carried out and glacier shrinkage has been estimated at an average of 8.1%. These studies have tried to identify the triggers of outburst floods, and better modeling may help to reduce risk and identify safe places for plant construction.

Policy recommendations that emerged from group discussion included the need to build public awareness of climate change impacts and to develop mechanisms to support and promote adaptation strategies. More participation in the development of climate response policy was recommended, as were more surveys of key indicators, especially in high altitude areas. The potential need for water storage facilities and water saving techniques should be examined, along with the impacts of climate change on infrastructure. It was considered that all sectors of the economy are likely to be impacted by deglaciation and more frequent extreme events. Key infrastructure will be at risk and measures should be taken to strengthen these. Diversification of crops, increases in water storage and building stronger institutions were all considered to be worthwhile. Other suggestions made by included:

- Establish small-scale industries requiring less water
- Develop an integrated and consistent mountain database
- Create a common framework for analysis and integration of data/information
- Assess the impact of land use changes on water resources in mountain regions
- Government should provide 'disaster shelters'
- Improve the standard of living in mountain communities
- Promote tourism as an employer both seasonally and throughout the year

4.4 Conclusions

While the results from the study in Nepal may provide some generic insight into how mountain communities may be influenced by deglaciation-induced changes, it must be noted that such impacts will vary considerably according to site specific variation across the region. In general, the findings can be summarized as follows:

- The impacts of climate change on water resources and the severity of this impact will vary with both spatial and temporal scales
- Millions of very poor people may be affected by significant changes in water availability and by more extreme events in the medium and longer terms
- People in higher altitudes are most likely to be effected by climate change
- Local communities are already aware of climate/weather-induced changes
- Appropriate mitigation and adaptation strategies are needed and community responses to these strategies may be influenced by social and economic factors

"Appropriate" here means what is relevant and suitable for the very diverse communities dependent on the water resources flowing from the Himalayas. The variation in both impact and response to climate change across the region cannot be overstressed. While some attempt has been made to examine these impacts at different scales, much more work needs to be done in mountain areas and across the region if a more comprehensive understanding of these issues is to be achieved. Results from the stakeholder workshops show that local people want to be much more involved in water resources planning and management than they are at present while at the same time there is a clear appreciation of the need for more strategic issues to be addressed at a larger scale.

As a result of the stakeholder consultation and dissemination workshops held at the local, national and regional scales, it is hoped that the project results and conclusions will be incorporated into the long term strategic plans of relevant authorities. By ensuring future water resource decisions are made in the light of better information about climate change, it is likely that the needs of the most vulnerable groups (women, children and the poorest of the poor) will be addressed.

Findings have been distributed in the form of a workshop CD distributed to all participants and in more formal "Policy Briefing Notes", drawn up in a participatory manner and disseminated to all relevant institutions and beneficiary groups.

5. Dissemination and Capacity Building

5.1 Dissemination to the general public

The outcomes of the SAGARMATHA project are not only of interest to decision makers and scientists but also to the general public, who are becoming increasingly aware of, and concerned about, climate change and its impacts on the environment. The threat of deglaciation has drawn the attention of many popular newspapers and magazines, as Figure 5.1 shows, and media response to the results presented at the project's recent stakeholder consultation workshops in India and Nepal demonstrates that public interest in the subject remains high. Journalists from national and regional newspapers and television channels attended the workshops and several articles subsequently appeared. A selection of the press-clippings can be seen in Figure 5.2. Television interviews given by project participants (Prof Collins, Prof Hasnain, Dr. Sullivan and Mr. Rees) during the workshop in New Delhi, appeared on the national DD2 News Channel in India on 28 April. The outcomes of the project were also reported in the New Scientist magazine (8 May, p7), but, unfortunately, the article misrepresented the results of the project suggesting that "after 40 years, most of the glaciers will be wiped out", leading to "severe water problems", "flood followed by famine". A letter, sent by Mr. Rees to rebut the claims of the article, was published in the magazine on 5 June (Figure 5.3).

While results of the project will be publicly disseminated via the SAGARMATHA world-wide-web site and various other publications (see Sections 5.3 and 5.4), it would useful if, when the Final Technical Report is approved by DFID, a joint press statement were to be issued by CEH and DFID, to ensure that the project outcomes are disseminated widely, and accurately, to the public.

5.2 Dissemination to the scientific community

The outcomes of the project are clearly of scientific interest. Project participants have already been invited to present their work at several meetings, workshops and symposia. In November, 2003, Mr. Rees and Dr. Sullivan presented interim results at the international workshop "Fragile Mountains Fragile People? Understanding "fragility" in the Himalayas", organized by the Bergen Mountain Forum in Norway.

Figure 5.1 *Recent press interest in deglaciation*

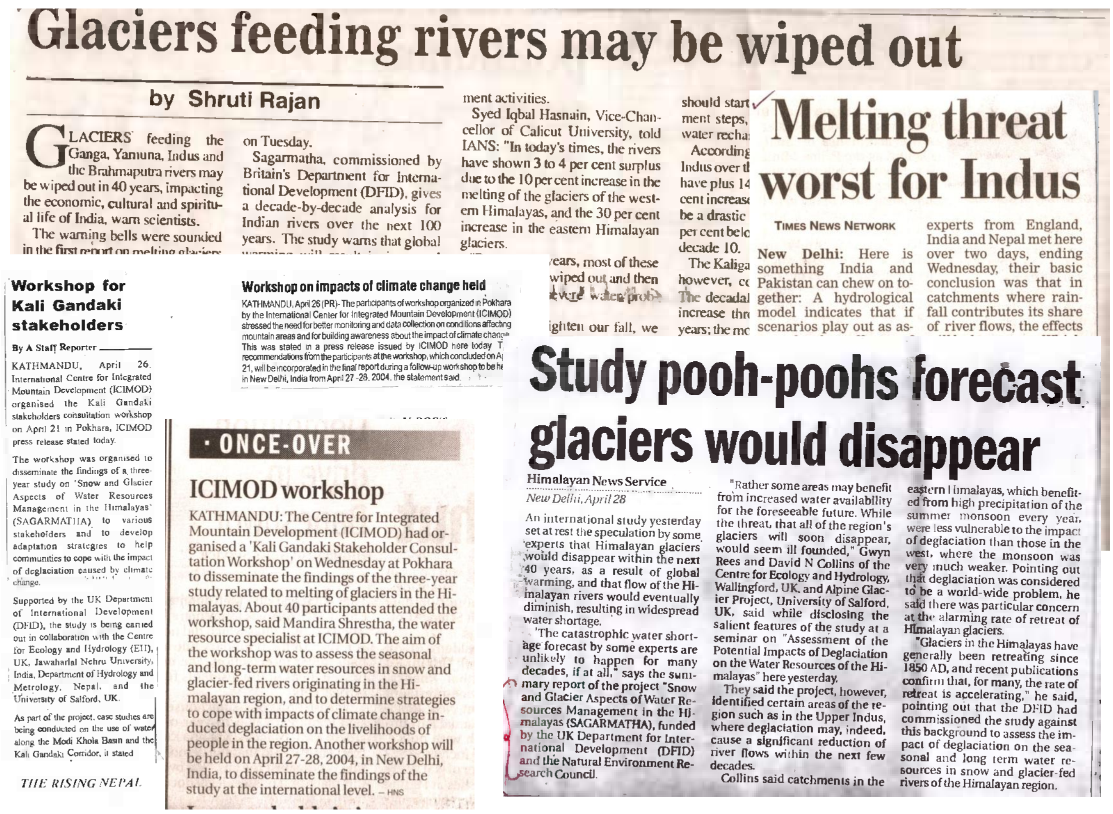

Figure 5.2 *Press clippings following the recent stakeholder consultation workshops*

Glacier meltdown

THE great rivers of northern India and Pakistan will run strongly for the next 40 years and then die away, bringing flood followed by famine. That was the grim message last week from the first decade-by-decade forecast for the rivers that drain the huge glaciers of the Himalayas.

The problem is global warming, which has already increased glacier melting by up to 30 per cent. "But after 40 years, most of the glaciers will be wiped out and then we will have severe water problems," says Syed Iqbal Hasnain of Calicut University, Kerala, reporting the results of a three-year study by British, Indian and Nepalese researchers.

The study finds the biggest impact in Pakistan, where the Indus irrigates half the country's crops. Flows here could double before crashing to less than half current levels by the end of the century. But the declining flows predicted for the Ganges will also throw into disarray a vast Indian government scheme to avoid drought by diverting water from the country's glacier-fed northern rivers to the arid south.

Studies have also forecast drinking water shortages in the Americas as glaciers melt in the Andes and Rocky Mountains.

New Scientist, 7 May 2004

No floods, no famine

From Gwyn Rees, Centre for Ecology and Hydrology

As lead author of the report referred to in your article on glaciers in the Himalayas, I was shocked that the results of our three-year study could be so grossly misrepresented (8 May, p 7). As our report "An assessment of the potential impacts of deglaciation on the water resources of the Himalayas" concludes, the widespread perception that the region's glaciers will disappear within 40 years is ill-founded.

In many areas, water shortages are unlikely to happen for many decades – if at all. Some areas may benefit from increased water availability in the medium term.

Catchments where glacial meltwater contributes significantly to the run-off, such as the upper Indus, appear to be most vulnerable to deglaciation. Eastern Himalayan catchments, benefiting from high summer monsoon precipitation, are less susceptible.

At no time did we suggest there would be a higher incidence of flooding, that famine would occur, or that an Indian government water-transfer scheme would be thrown "into disarray". The individual quoted in the article, though a member of our study team, clearly presented his personal view of the situation.

Wallingford, Oxfordshire, UK

New Scientist, 5 June 2004

Figure 5.3 *New Scientist coverage of SAGARMATHA*

A report of the workshop was recently published in the journal, Mountain Research and Development (Vetaas and Knudsen, 2004). Mr. Rees also presented the work of the project at the Management Bureau meeting of the International Commission for Snow and Ice (ICSI) at the Scott Polar Research Institute in Cambridge in November 2003, and, consequently, was invited to present a paper at an ICSI organized conference on "Glacier Shrinkage and Consequences for Water Resources" in Huaraz, Peru, at the beginning of July 2004. The conference proceedings are to be published in a special issue of the Hydrological Sciences Journal. In December 2003, Mr. Rees was invited to the WMO World Climate Programme – Water (WCP-Water) Expert Meeting in Wallingford and, again, presented interim results from the project.

Project participants have further plans to submit scientific papers on the results to several international peer-reviewed journals and conferences. Papers are envisaged for the journal of Mountain Research and Development (an overview paper), the Hydrological Sciences Journal (a paper on the regional hydrological model) and the Hydrological Processes Journal (a paper temperature lapse rates in the Himalaya). Posters and papers are also planned for the International conference of Hydrology of Mountain Environments, in Berchtesgaden, Germany, in September 2004, and at the International Association of Hydrological Sciences (IAHS) symposium on the "Contribution from Glaciers and Snow Cover to Runoff from Mountains in Different Climates" in Brazil in April, 2005.

The SAGARMATHA project is a contribution to the activity of Snow and Glacier Group of the Hindu Kush – Himalayan Himalayan (HKH) FRIEND (Flow Regimes from International Experimental and Network Data) project. As such, it is a contribution to the 6th International Hydrological Programme (IHP-VI) of UNESCO. Subject to DFID approval, the project will publish Volumes 2 and 3 of the Final Report, in the UNESCO Technical Documents in Hydrology series, which will be distributed widely to national IHP committees throughout the HKH region and the rest of the world. The results will also be shared with the participants of the HKH-FRIEND project and with members of the ICSI Working Group on Himalayan Glaciology.

5.4 Dissemination to decision makers

The stakeholder consultation workshops described in the previous chapter (Chapter 4), and in Volume 3, were the primary mechanisms for informing decision makers from the region of the outcomes of the project. A Technical Briefing Note, summarizing the results of the hydrological assessment was prepared for, and distributed at, the workshop. A copy of the briefing note can be seen in the "Background Documents" volume. A series of A0-size posters were also prepared and displayed, with smaller, A3-size copies handed out to participants. A CD, comprising the presentations made during the workshops, has been distributed to all participants

Unfortunately, representatives from China and Pakistan were unable to attend the regional workshops in New Delhi. However, progress with the project had earlier been presented to two Chinese delegations who visited CEH in September 2003 and January 2004: the first, from the Ministry of Water Resources; the second, from the National Development and Reform Commission (NRDC). Both delegations showed expressed interest in conducting similar studies in China. CEH has also maintained contact with the China Institute of Water Resources and Hydropower Research and the Lanzhou Glaciology Institute during the course of the project, and will be supplying both with copies of the FTR.

Pakistan's inability to attend the workshop was particularly disappointing, due to the implications of the results for the Indus basin, but CEH have since been in contact with the Islamabad-based Global Change Impact Studies Centre (GCISC), and have supplied them with a copies of the technical reports that were distributed at the workshop. A positive response was obtained from GCISC, and they are enthusiastic to further investigate what is happening in the Upper Indus.

Stakeholder comments have resulted in the potential adaptation strategies being finalised and presented in the two Policy Briefing Notes shown in Annex 3. Subject to DFID approval, it is intended that these will be distributed to all relevant ministries, planning authorities, non-governmental organizations (NGOs) and others involved with water resources management in the region. This activity will be undertaken by ICIMOD, which has a remit "to ensure that new knowledge is disseminated widely in the region", and other project participants.

5.5 The SAGARMATHA Project WWW site

Subject to DFID approval, the Final Technical Report, together with relevant technical reports, will be made publicly available, as PDF documents, on the project's world-wide-web (WWW) site. The site was established at the beginning of the project, and, as can be seen in Figure 5.4, provides a brief description of the SAGARMATHA project and its objectives. The site has recently been updated to include a summary of the project's results and details of how to obtain the dissemination software.

Figure 5.4 *The SAGARMATHA WWW site*

5.6 Dissemination Software

The dissemination software enables the hydrological forecasts of future decadal flows of the different climate change scenarios to be easily viewed for any river stretch in the study area. The software, named “FORWARD-HIMALAYA”, for “Forecasts of Water Resources under Deglaciation in the Himalaya”, was developed jointly by JNU and CEH, according to the Software Requirements Specification produced in March 2003 (see Volume 4, “Background Papers”). The application was written in Visual BASIC, and uses the ESRI Map Objects extension to enable users to, amongst other things, zoom in and out, and pan the 900, or so, maps generated from the regional model (Figure 5.5). The software requires a minimum of 565 Mb of disk space to run and a PC configured with the Windows 95 (or higher) operating system, a minimum of 32 Mb RAM, a Pentium compatible CPU rated at 133 MHz or higher, a super VGA monitor and graphics card and a 24-speed CD-ROM drive. Due to its large size, the software will only distributed on CD and will be available on request via e-mail requests from the WWW site. A CD-ROM containing the software and a User Guide are presented in Annex 3.

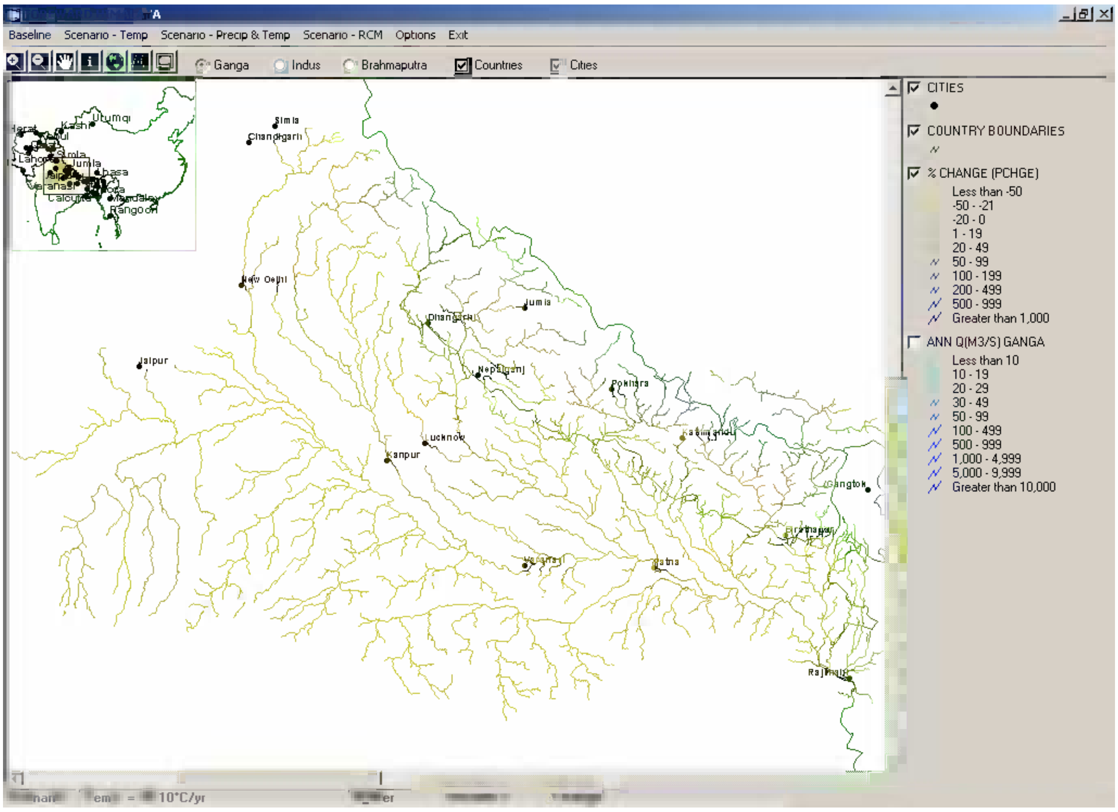

Figure 5.5 *The User Interface of the FORWARD-HIMALAYA software*

5.7 Capacity building and knowledge transfer

The research capacity of Indian and Nepalese partners to undertake regional scale hydrological modelling has been bolstered through their involvement in the project and their exposure to modern GIS technologies, advanced statistical software and modelling methods that were used. More tangibly, the 2 automatic weather stations purchased by the project will support the continuing long-term monitoring of two important study glaciers in the region, and will contribute to our future understanding of how glaciers respond to climate change. In addition, the two post-graduate students from the region, Mr. Shrest Tayal and Mr. Shiba Prasad Rijal, who benefited from project support, have made good progress with their respective studies, and both are expected to submit their candidature for PhDs within the next 18 months.

Of course, the most important "capacity building" outcome of the project will be the improved ability of the region's stakeholders to both understand the threat of deglaciation and adapt appropriately to the impacts. The dissemination activities, described in this chapter, will create awareness among policy makers, planners, decision makers and water-users and will, hopefully, ensure that the project outcomes will be incorporated into the long term strategic plans of relevant authorities. With such improved understanding of the effects of climate change on the region's water resources, the relevant authorities will be better equipped to cope with the negative impacts and safeguard the livelihood of the many millions of people living downstream.

6. Conclusions

There is ample evidence of deglaciation occurring in the Himalayas, and there has been much speculation how the 500 million inhabitants of the Indus, Ganges and Brahmaputra river basins will be affected. SAGARMATHA has been the first project to attempt to quantify the impacts of deglaciation on the water resources of the region as a whole, and the consequences for downstream communities.

To achieve its objectives, the project uniquely gathered an international team of world-renowned hydrologists, glaciologists and environmental economists. A new regional hydrological model was developed by the project and applied to a variety of climate change scenarios to determine the potential impacts of deglaciation on future river flows in the Indus, Ganges and Brahmaputra river basins. The model incorporated a particularly innovative "generic glacier" approach that enabled both the melt-water contribution of many glaciers, and their rate of deglaciation, to be represented. As with the development of any new model, there is always considerable scope for improvement. Further research is needed to define optimal values for the various model parameters, while improvements could be made to the data used that "drive" the model: climatological data that are more representative of conditions at high elevations in mountains, for instance. Meanwhile, the approach of applying climate change scenarios uniformly by annual increments for every year of a 100-year model run could be improved in future by introducing a higher degree of inter-annual variability. Despite these limitations, the model gave encouragingly plausible results, from what is known of the dynamics of glaciers and the climate of the Himalayas.

According to the model results, for many areas, the catastrophic water shortages forecast by some experts are unlikely to happen for many decades, if at all. Rather, some areas may benefit from increased water availability for the foreseeable future. While the threat that all of the region's glaciers will have disappeared within 40 years would seem ill-founded, the project identified certain areas of the region, such as in the Upper Indus, where deglaciation may, indeed, cause a significant reduction of river flows within the next few decades. Clearly this would have serious consequences for future water availability and use throughout the basin and measures to mitigate the potential impact should be considered urgently.

The results further show that impacts of deglaciation vary considerably across the region and within catchments. Highly glaciated catchments, and catchments where melt-water contributes significantly to the runoff, have been shown to be most vulnerable to deglaciation. Results from the different focal-areas indicate the very important role precipitation has in protecting glaciers from melting and rapid mass loss: a thick covering of snow resulting from a strong monsoon would insulate the glacier and delay melt, whereas, a weak monsoon would expose a glacier to melting earlier and for longer. In glaciated catchments where precipitation is relatively high, the impacts of deglaciation diminish rapidly downstream, as the runoff contribution from rainfall over the non-glaciated part of the catchment quickly swamps the melt-water contribution. Where precipitation is low, the melt-water contribution to runoff, and, hence, the impact of deglaciation, remains proportionately high for a significant distance downstream. The regional picture portrayed here, does not necessarily apply to all glaciers throughout the region, and it is probable that some glaciers in the less vulnerable areas are already on the verge of disappearing, which would cause imminent difficulties for communities downstream. Readers should also be careful how they interpret these results. Whilst some alarmist claims can be discounted with confidence, the timing and magnitude of impacts, should not be taken too literally: they show results of various hypothetical scenarios applied to a conceptual model, and, as such, only provide an indication of what might happen. Much work remains, through the continuation of monitoring and further research, to ensure the future impacts of deglaciation and climate change on water resources are better understood.

An assessment of the impacts of deglaciation on the livelihoods of communities was conducted at three spatial scales: at a community level; at a basin level; and regionally. Over 100 local "stakeholders" contributed to this consultation-based activity, identifying the potential threats from climate-change induced deglaciation and suggesting possible strategies for adapting to them (the threats). It too concluded that the impacts of climate change on water resources, and the severity of this impact, will vary with both spatial and temporal scales. And, while millions of very poor people may be affected by significant changes in water availability, people living at higher altitudes are most likely to be effected by climate change. As well as outlining various reactive strategies, such as, changing cropping patterns, the variety of crops, animal husbandry techniques, improved water saving, and so on, the consultations came up with a selection of longer-term pre-emptive strategies that would help mitigate any future impacts, including: building public awareness of climate-change and its effects on the environment; improving systems of data collection; developing sustainable water management and planning strategies; and improving communication and infrastructure in mountain areas. The recommendations that emerged from the four stakeholder consultation workshops held in Nepal and India in March and April 2004 were summarized in two Policy Briefing Notes (Annex 3). These will be distributed to relevant organizations in the region, once they are approved by DFID.

A considerable amount of interest has been shown in the outcomes of the project by the general public, by the scientific community and by regional stakeholders. The dissemination activities, outlined in the previous chapter, should ensure that the project's results will reach as wide an audience as possible. It is hoped that, ultimately, this will improve awareness among policy makers, planners and decision makers in the region, and will help them to adapt appropriately to the impacts of deglaciation and safeguard the livelihoods of the many millions of people who rely on the melt-water resources of the Himalayas.

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Annex 1: Logical Framework

The SAGARMATHA Logical Framework (last update: 24.4.03)

Narrative summary	**Measurable indicators**	**Means of verification**	**Important assumptions**
Goal: (F1):	(5 lines) (F1):	(5 lines) (F1):	No input required.
Purpose: To assess the seasonal and long term water resources in snow and glacier fed rivers originating in the Himalayas and to determine strategies for coping with impacts of climate change induced deglaciation on the livelihood of people in the region	Operational use of software package for the seasonal planning of water resources in the region. Incorporation of recommendations in the long-term strategic plans of regional authorities	Registration of users of operational software and log of calls relating to the software. Reference to project recommendations in regional planning documents.	(Purpose to goal) F1): Reliable forecasts of seasonal water resource availability are required in the region. Evidence of world-wide climate-related deglaciation means there is a need to assess the implications for water resources management.
Outputs: 1.INCEPTION REPORT	Report completed by 2/02	Report (#1) posted onto project WWW site, copied to DFID.	(Output to purpose) Project builds on existing knowledge and data
2a.PROJECT DATABASE	Database complete and copied to partners by 6/02	Summary of database (#2) on WWW site and copied to DFID.	
2b. GLACIER MONITORING EQUIPMENT FOR INDIA AND NEPAL	2 x Automatic Weather Stations plus other equipment procured and installed by 4/02	Purchase orders /receipts and installation reports copied to DFID.	Equipment supplied by the project will contribute to on-going long term glacier monitoring in the region
3. REGIONAL HYDROLOGICAL MODEL	Regional hydrological model produced by 3/03.	Technical report (#3) describing the model and test results posted on WWW site, copied to DFID.	Snow/glacier melt integral part of regional hydrological model
4. WATER RESOURCES FORECASTS	River flow forecasts produced using contemporary data and climate change scenarios by 8/03.	Results included in Technical Report (#3).	Uncertainty about climate change accommodated by the use of IPCC recommended scenarios
5. SOFTWARE PACKAGE	Beta-tested software package on CD-ROM completed by 2/04	Software and User Guide to be distributed at the 2 training workshops	Potential users have the computing capacity to run the software.
6a. LIVELIHOOD IMPACTS REPORT	Impacts assessment report completed by 9/03 and presented at workshop in 2/04	Report (#4) posted on WWW site, copied to DFID, distributed and discussed at the 2 training workshops.	Derogation of water resource due to deglaciation is a concern to regional planning authorities and other stakeholders, ensuring their active involvement.
6b. ADAPTATION STRATEGIES	Adaptation strategies distributed as a consultation document to local stakeholders by 2/04 and finalised following workshops by 3/04	DFID receives copy of consultation document (#5) and finalised strategies (#6).	
7a. KNOWLEDGE TRANSFER TO LOCAL STAKEHOLDERS	2 x stakeholder workshops conducted (Nepal and India) by 03/04	Record of attendance, recipients of software and other material, comments from training appraisal forms detailed in workshop report.	Local stakeholders, involved from the outset of the project, employ software and recommendations operationally.
7b. KNOWLEDGE TRANSFER TO INTERNATIONAL COMMUNITY	Project WWW site publicly available by 8/01 Articles & papers published within 3 years of project completion	WWW site “hits” recorded at CEH Reference list maintained at CEH.	Project will improve knowledge base for effective management of water resources threatened by deglaciation
8a. PROGRESS REPORTS 8b. MINUTES OF MEETINGS 8b. FINAL REPORT	Progress reports every 6 months Minutes following each meeting Final Report completed 3/04	Reports and minutes submitted to DFID on time.	

Activities: 1.INCEPTION STUDY a) Lit. Review of methods b) Identify available data	Inception Report	Technical Report (#1) produced	(Activity to output)
2. BUILD PROJECT DATABASE a) Define database structure and populate database with river flow data, snow/ice cover data, climate data, field data, etc.	Database built, populated with relevant data, and copied to partners	Database summary presented in Technical Report (#2); database installed on partners' systems	The project will have access to the large amount of data that is available in the region. Partners have sufficient hardware and software capacity
b) Provide field equipment	Equipment procured and installed	Receipts for equipment	
3. DEVELOP REGIONAL HYDROLOGICAL MODEL Development of regionalised model incorporating snow/glacier melt module	Model verified by comparison with test site data.	Regional hydrological model described and results presented in a Technical Report (#3)	Relationships can be found between snow/glacier cover and river flow; hydrological and remote sensing data will be used to test the model
4. APPLY REGIONAL HYDROLOGICAL MODEL a) Derivation (from DEM data) of flow accumulation grid for routing	Flow accumulation grid loaded in GIS database	Accumulation grid documented in Technical Report #3.	USGS GTOPO30 topographic data continues to be available
b) Application of contemporary data and climate change scenarios	Water resources forecasts produced for given data inputs	Model results reported in Technical Report #3.	IPCC climate change scenarios will be used to forecast future river flows
5. SOFTWARE DEVELOPMENT a)Define software requirements	Requirements specification agreed between partners	Requirements specification copied to DFID.	JLNU able to deliver software as specified
b)Implementation of regional model in software package by India sub-contractor (JLNU)	Alpha-tested software developed and User Guide presented for Beta-testing	System design specification, system docs, source code and executables forwarded to CEH.	
c) Beta-test at DHM and CEH	Test logs kept and User Acceptance forms signed	Test logs and Acceptance forms notified to DFID	
d) Packaging software on CD-ROM and production of user guide	CD-ROM and User Guide produced	Software and User Guide submitted to DFID	
6. LIVELIHOODS IMPACTS & ADAPTATION STRATEGIES a)Appoint local PhD student; study impacts on livelihoods.	Local PhD student appointed	Appointment reported to DFID	Suitable candidate available
b)Establish contact with stakeholders to initiate consultations	Record of correspondance / meetings collated	Documentation available for inspection by DFID	ICIMOD able to identify stakeholders to be included in consultation, and to arrange interviews.
c)Qualitative analysis of water resource usage: fact-find and consultation with stakeholders	Progress report	Summary progress report copied to DFID.	
d)Assessment of impacts of changes in water resources using model forecasts	Report of impacts assessment for a range of scenarios completed.	Impacts assessment report (Technical Report #4) copied to DFID.	Hydrological predictions can be interpreted succinctly in terms of quantitative and qualitative indicators of impacts
e)Development of coping strategies to mitigate impacts	Consultation document distributed.	Draft strategies copied to DFID (Technical Report #5).	
f) Finalise adaptation strategies	Finalised adaptation strategies produced.	DFID receives copy of finalised document (Technical Report #6)	
7. KNOWLEDGE TRANSFER a)Prepare and conduct 2 workshops for local stakeholders	Project software, reports and recommendations collated and distributed at workshops	Attendance records and reports of workshops.	Stakeholder involvement in the project encourages active participation in the workshops
b)Develop WWW site for technical reports and other project information	WWW site developed and populated with project output	WWW address notified to DFID	WWW site location publicised effectively (e.g. via DFID, IHP, IAHS newsletters etc.)
c)Dissemination of results to international programmes, journals and conferences	Articles or papers published in technical reports, newsletters, journals and conference proceedings.	Publication record and reference list maintained by CEH	Technical aspects of the project continue to be of international interest
8. PROJECT MANAGEMENT a) Contract management b) Schedule & monitor activity c) Project meetings d) Project reporting	Financial statements from CEH Timely delivery of outputs and progress reports	Financial statements, periodic progress reports, meetings' minutes & Final Report to DFID.	Co-operation with partners will continue throughout the project; no delay in contract signing or other admin matters; no major political or economic upheaval occurring during the study period.

Annex 2: Output to Purpose Summary Report

OUTPUT TO PURPOSE SUMMARY REPORT			
Title: SAGARMATHA (R7980)	**Countries: INDIA/NEPAL/PAKISTAN/BANGLADESH**		**MISCODE:**
Report No. 1/2004	**Date**: 30/6/04	**Project start date:** 01/3/2001 **Project end date:** 31/3/2004	**Stage of project:** Year 3 of 3
Goal statement: *W1 Improve the assessment, developments and management of water resources*			
Purpose: To assess the seasonal and long term water resources in snow and glacier fed rivers originating in the Himalayas and to determine strategies for coping with impacts of climate change induced deglaciation on the livelihood of people in the region			
Outputs:	**OVIs:**	**Progress:**	**Recommendation/actions:**
1. Inception report	Report completed by 06/2001	Report completed February 2002, approved by DFID September 2002..	
2a. Project database 2b. Glacier monitoring equipment	Database complete and copied to partners by 03/2002 2 x Automatic Weather Stations procured and installed 06/2001	Database development completed and distributed in November 2002 Contractual delays resulted in postponement of AWS procurement. Both AWS installed at, or near, glaciers in India and Nepal by June 2002.	
3. Snow/glacier model 4a. Regional hydrological model 4b, Water resources forecasts	Model completed by 06/2002 Regional hydrological model by 12/02. River flow forecasts produced using climate change scenarios by 02/03.	Model developed and applied to different climate change scenarios and described in Technical Note 2, April 2003. Results published in Technical Report, distributed at stakeholder consultation workshops in April 2004, and feature in Volumes 1 & 2 of the Final Technical Report.	Future research required to improve the parameterization of the model(s). Apply models with improved datasets, as they become available.
5. Software package	Beta-tested software package completed by 12/03	FORWARD-HIMALAYA Software developed and tested, available on CD ROM in Annex 4 of this report, available free-of-charge via the SAGARMATHA WWW site	
6a. Livelihood impacts report 6b. Adaptation strategies	Impacts assessment report completed 09/03, presented at workshop in 02/04 Adaptation strategies local stakeholders by 09/03, finalised 03/04	Results of stakeholder surveys presented at consultation workshops in March & April 2004; finalised adaptation strategies, including Policy Briefing Notes presented in Volumes 1 & 3 of this Final Technical Report	Subject to DFID approval, Policy Briefing Notes to be distributed to relevant authorities in the HKH region.
7a. Knowledge transfer to local stakeholders 7b. Knowledge transfer to international community	2 x stakeholder workshops conducted by 02/04 WWW site publicly available by 06/01; Articles and papers published within 3 yrs of project completion	4 stakeholder cons7ulation workshops conducted in March & April 2004; further dissemination activities outlined in Chapter 5 of this report. Subject to DFID approval, Technical Reports and Policy Briefing Notes will be made freely available in PDF format of the SAGRMATHA WWW site FORWARD-HIMALAYA dissemination software available on request via the project web-site	Joint press statement by CEH & DFID to world's press/media. Subject to DFID approval, Technical Reports and Policy Briefing Notes to be placed on SAGARMATHA WWW site,
8a. Progress reports 8b. Minutes of meetings 8c. Final report	Progress reports every 6 months Minutes following each meeting Final Report completed 03/04	Project management activities outlined in Chapter 2 of this report. Copies of progress reports and meetings' minutes in Volume 4. Final Technical Report completed June 2004	
Purpose:	**OVIs**	**Progress:**	**Recommendations/action**
To assess the seasonal & long term water resources in snow & glacier fed rivers originating in the Himalayas & to determine strategies for coping with impacts of climate change induced deglaciation on the livelihood of people in the region	Operational use of software package for the seasonal planning of water resources in the region. Incorporation of recommendations in the long-term strategic plans of regional authorities	Project completed with all objectives met. Uptake of recommendations by regional authorities is beyond the control of the project, but the proposed dissemination activities (Chapter 5) should ensure widespread awareness of the results.	

Annex 3: Policy Briefing Notes

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL
DFID Department For International Development
ICIMOD
His Majesty's Government of Nepal
Department of Hydrology & Meteorology
JAWAHARLAL NEHRU UNIVERSITY

Mountain Livelihoods, Water Resources and Climate Change in Nepal

POLICY BRIEFING NOTE

The nature of mountain livelihoods

In Asia, 65% of the rural population live in upland areas, depending on farming, small scale industry, handicrafts, tourism and external remittances. While there is considerable cultural and social diversity in such regions, people often face the same kinds of threats and challenges. The topography and ecology of the region is also highly diverse, giving rise to many different microclimates and geographical conditions impacting on how people live, but in spite of adversity, people generally tend to be resilient and resourceful. In the upland areas of Nepal, livelihoods depend predominantly on animal husbandry, cultivation of medicinal plants, and the utilisation of non-timber forest products. Small scale hydropower and water mills are used to support communities within these mountain catchments, and domestic water supplies are almost always taken from springs, small tributaries or wells, rather than from the main rivers themselves, due to the fact that communities are usually located on steep valley slopes away from the river. Irrigation is important in some areas, and rivers originating in these upland zones provide water for people and the economy for hundreds of miles downstream.

Current problems in mountain communities

Poverty is a major problem for upland communities, and rural depopulation is a direct consequence of that, as young people leave the area in search of work. Because of the high levels of unemployment, non-cash income is important, and there is much dependence on the utilisation of open-access natural resources. Forests and water play an important role, but concern has been raised about environmental degradation, often characterised by landslides and floods. Unpredictability of seasons creates a problem for farmers, and people feel that outdated and inappropriate agricultural techniques currently in use should be revised. Lack of infrastructure such as irrigation schemes and transport, and poor educational facilities are considered a problem for these communities, along with lack of markets and political instability. In the mountain communities of Nepal, and other countries in the HKH region, people have considerable ecological knowledge, and from experience, have good understanding of how climate variation can influence local livelihoods. There is much scope for drawing on this local and indigenous knowledge, to support the development of more integrated and holistic resource management policies, in which communities are keen to be involved.

Research findings

1. Integrated hydrological modelling has suggested possible changes in water availability across the Himalayan region, as a result of climate change. Rising global temperatures are bringing about a process of deglaciation, directly impacting on river flows, initially causing an increase in flow rates in many areas, followed later by a reduction, as glacier melting rates decrease.

2. In the east of the region, increased volumes of water flowing out of mountain areas are likely to increase flows downstream, where precipitation is high during monsoon seasons. In western areas of the region, however, where rainfall contributes much less to local conditions, impacts of changes in snow melting rates will be more severe, resulting in significant reductions in water availability in the longer term.

3. Across Nepal, both immediate and longer term impacts may be felt, but not with the severity felt in other parts of the region. This is mainly due to the volume of snow and ice available at high elevations in Nepal.

4. These changes in water availability are likely to impact more on communities in upper parts of river basins, and this will have both regional and global implications. As a result, there is a need for the development of suitable and acceptable adaptation strategies, to address issues which may impact on the health and welfare of diverse human populations across the region.

5. Participatory consultation with a range of stakeholders highlighted the need for better, more equitable water allocation and management strategies, along with more public and professional awareness-raising campaigns.

POTENTIAL ADAPTATION STRATEGIES

Following extensive consultation at the local, national and regional levels, a number of adaptation strategies have been identified for further investigation:

- Develop management strategies to cope with changes in water availability
- Review approaches to techniques in the design of infrastructure, dams, irrigation schemes etc.
- Investigate change in cropping patterns, identify new, less climate-sensitive varieties
- Promote social networks of knowledge transfer and support
- Evaluate changes in location of fishing activities, development of community fish ponds
- Investigate appropriate alternative locations of tourism activities and options
- Review animal husbandry techniques, and development of new breeds
- Migration – need to prevent further rural depopulation

POLICY RECOMMENDATIONS[1]

- Build awareness of the impacts of climate change
- Encourage more participation in the development of climate response policy
- Promote better monitoring and data collection about conditions in upper mountain areas
- In key areas, introduce participatory surveys on selected indicators of climate change
- Develop mechanisms to support and promote adaptation strategies
- Investigate potential for water saving techniques
- Encourage the development of experimental cropping (in conjunction with the Ministry of Agriculture)
- Investigate potential for early warning
- Investigate scale of impacts on infrastructure in key basins
- Assess appropriate infrastructure responses
- Investigate potential need for water storage facilities
- Facilitate the introduction of a comprehensive (environmentally friendly, participatory, equitable) water use act by the government
- Support more integration and coordination between government departments, NGOs, etc., and development of a comprehensive mountain database
- Encourage the implement of participatory catchment conservation projects, and afforestation programmes near glaciers
- Promote and foster existing social heritage in tourism development
- Identification of risk levels associated with hydrological accidents and other natural disasters, in specific geographical locations
- Enable more participation by women and marginalized people, including lower caste groups, and encourage their empowerment and support
- Research findings should be disseminated widely to people at all levels of society, not just policy makers. Children are important recipients of knowledge about climate change impacts and adaptation strategies

[1] These are based on consultation outputs from local and national stakeholders. Full details can be found in Sullivan et al. (2004), *An assessment of the potential impacts of climate-induced deglaciation on communities in the Hindu Kush Himalaya*. CEH, Wallingford, UK.

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Full details of this work can be found in the SAGARMATHA Final Technical Report, Rees et al, 2004, CEH. Wallingford, UK.

Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL
DFID Department for International Development
His Majesty's Government of Nepal Department of Hydrology & Meteorology
JAWAHARLAL NEHRU UNIVERSITY

Climate Change, Water Resources and Livelihoods in the Himalayas

POLICY BRIEFING NOTE

Water resources and mountain systems

There is compelling evidence that climate change is a widespread problem with serious consequences for water resources around the world, and more than half of humanity relies on the freshwater that accumulates in mountains. The Hindu Kush-Himalayan (HKH) mountain region stretches across eight countries, is home to more than 140 million people, and influences the lives of three times as many in the plains and river basins below. The snow and glaciers of the HKH provide up to 90% of the lowland dry-season flows of the Indus, Ganges and Brahmaputra rivers and their vast irrigation networks. Scientists are studying the retreat of Himalayan glaciers and, although uncertainty exists, the consequences of deglaciation on water resources in the region could have serious consequences for the environment, national and regional economies, and for the day to day lives of many millions of people. To cope with these predicted and potential changes, and in the face of the increasing demands on water resources from growing populations and economic development, the effective management of mountain water resources is essential. Policies and adaptation strategies need to be developed and achieved in consultation with different stakeholders, considering the ideas, experience and knowledge of local people and scientists, as well as government and non-government organisations.

Current issues in mountain communities

Communities in mountain regions face many problems such as poverty and inequity, depopulation, unemployment, a lack of healthcare and educational facilities, and poor infrastructure. People across the HKH region share these problems which are exacerbated by environmental issues such as the unpredictability of seasons, extreme events (e.g. floods, storms, droughts), deforestation, soil erosion, and a lack of capacity in natural resource management. Water is vital for all kinds of economic and livelihood activities and any changes in the quantity, availability and quality of water resources would add to the current social, economic, and environmental problems faced by populations across the region.

Research findings

The SAGARMATHA project[1] has made an assessment of the potential impacts of deglaciation on the water resources of the Himalaya and on the livelihoods of people in the region. This has been achieved through the development of hydrological modelling and livelihood assessment and with the involvement of many stakeholders across the region. The studies have found that:

1. Changes in water availability in Himalayan Rivers as caused by deglaciation can have direct and indirect impacts. An increase in river flows can affect human activities in many ways through flooding, landslides and the destruction of water delivery systems. Reduced water availability creates water shortages for water-dependant activities such as agriculture, fisheries, hydropower, industry, domestic water supply and water transportation.

2. For many areas, the catastrophic water shortages forecast by some experts are unlikely to happen for many decades, if at all. Rather, some areas may benefit from increased water availability in the medium-term. Areas where glacial meltwater contributes significantly to river flow, such as in the upper Indus, however, appear to be vulnerable to deglaciation and this could have serious consequences for water availability and use throughout the basin. Eastern Himalayan areas, benefiting from high summer monsoon rainfall, are less susceptible to droughts, but more likely to experience flooding.

3. In the longer term, a reduction in water supply from the mountains could affect the economy of the region by limiting the energy from hydropower plants and hampering industrial productivity. However, while deglaciation may hinder economic development nationally, the impacts are likely to be hardest felt at the local level by the most vulnerable in society, particularly the women and children of poor families, and the communities most vulnerable are those living at higher and middle altitudes and dependent on their crops, livestock, and small-scale industry.

4. The impacts of deglaciation, and other effects of climate change, will vary considerably with time and specific location across the HKH region. The research has also highlighted the uncertainty associated with climate research and emphasises that care must be taken when interpreting the results.

[1]Rees *et al*., *SAGARMATHA: Snow and Glacier Aspects of Water Resources Management in the Himalayas*, CEH Research Report 2004.

POTENTIAL ADAPTATION STRATEGIES

Following extensive consultation at the local, national and regional levels, a number of adaptation strategies have been identified for further investigation:

- Improve long-term monitoring, data collection, and modelling of the links between climate impacts and hydrological regimes
- Carry out research into alternative cropping patterns and crop varieties
- Increase water storage capacity
- Promote water saving techniques in all sectors
- Develop early warning systems to give longer warning of forthcoming events, hail storms etc.
- Diversify employment opportunities in upland areas
- Improve and expand planning of communications & infrastructure to take account of potential impacts of changes in river flows
- Develop integrated, equitable & sustainable water resource management strategies
- Promote institutional networking and development
- Empower women and marginalized communities to have more inputs into water policies

POLICY RECOMMENDATIONS[2]

It is considered that deglaciation could impact on all sectors of the regional economy and on many people's livelihoods and that mechanisms to support and promote appropriate adaptation strategies need to be developed to face these challenges. These strategies will need to be site-specific and aimed at creating sustainable livelihoods for all people across the HKH region, particularly the poorest.

- There is a need to improve systems of data collection and modelling to reduce uncertainty
- In key areas, introduce a survey on selected indicators of climate change, to improve monitoring of conditions in upper mountain areas
- Investigations should be carried out to assess the potential for the introduction of water saving techniques, and to identify the need for water storage facilities
- Assessments of the scale of impacts on infrastructure in key basins is needed
- Development of experimental cropping and new crop types are recommended
- General awareness-raising of climate change impacts is needed, and specific training about climate change mitigation should be given to key persons and institutions
- Alongside scientific and technical approaches, it is particularly important to take a more participatory approach in the development of climate response policy
- There is a need for an assessment of the potential benefits of early warning systems for extreme events, and providing better communication of forthcoming hailstorms etc.
- Long-term and appropriate strategies are required that will build stronger institutions and improve water management to take account of competing needs

[2] These are based on consultation outputs from local and national stakeholders. Full details can be found in Sullivan et al. (2004) *An assessment of the potential impacts of climate-induced deglaciation on communities in the Hindu Kush Himalaya*. CEH, Wallingford, UK.

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Annex 4: Dissemination Software and User Guide

SAGARMATHA

Snow and Glacier aspects
of Water Resources Management
in the Himalayas

FORWARD-HIMALAYA

User Manual

June 2004

Introduction

The Forward-Himalaya software package is a Geographic Information System (G.I.S.) designed as part of a project called SAGARMATHA (Snow and Glacier Aspects of water Resources Management in the Himalaya). A major part of the project was the development of a regional hydrological model, incorporating an innovative snow-and-glacier-melt component. The software provides a graphical representation of the predicted effects of deglaciation on future water resource availability in three test river basins. This software manual provides the User with a step-by-step guide on installing and setting up the software application and explains the software's main features and layout.

Hardware requirements

Operating systems:	Window 95 or higher
RAM:	32Mb or above
Processor:	133MHz or higher
Graphics:	VGA or higher resolution monitor (Graphics card required)
CD ROM:	24 speed
Hard disk:	560Mb of free space

Definitions and Conventions

For the purposes of this document a number of conventions and definitions have been adopted. These conventions are explained as follows:

Convention	Explanation
CAPITALS	Keys on the computer keyboard are shown in capitals, for example the escape key is shown as ESC
[menu choice]	Functions can be accessed via pull-down menus or clicking on the appropriate icon/tab. Where menus are referenced, menu choices are indicated by square brackets. For example [Apply]
Bold	Indicates that this text will appear on the Window currently displayed.
	Greyed out menu items indicate that this function is not available to the current User.

Definitions and terminology used throughout this document are listed below.

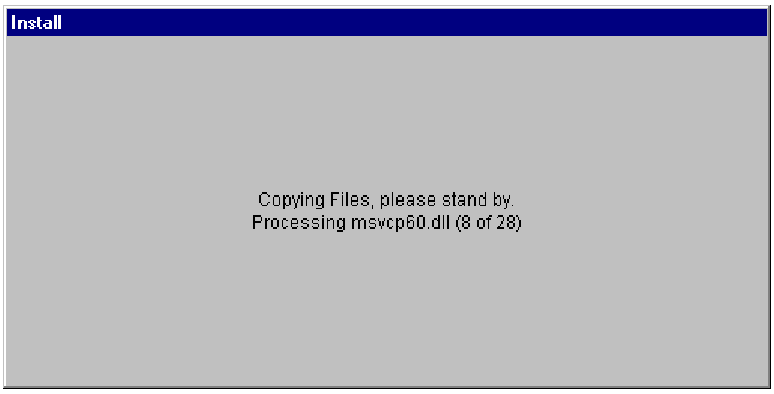
Term	Definition
Features	Objects represented on maps as overlays. Each feature has a location, shape and symbol. For example, abstraction points, discharge points, impoundments.
Attributes	More detailed information about the feature, which is archived in the database.
Layers	Visual images displayed as 'maps' represent spatial data sets of either vector or raster data. Layers may be overlaid, for example, river networks can be shown on top of country boundary maps.

Installation Procedure

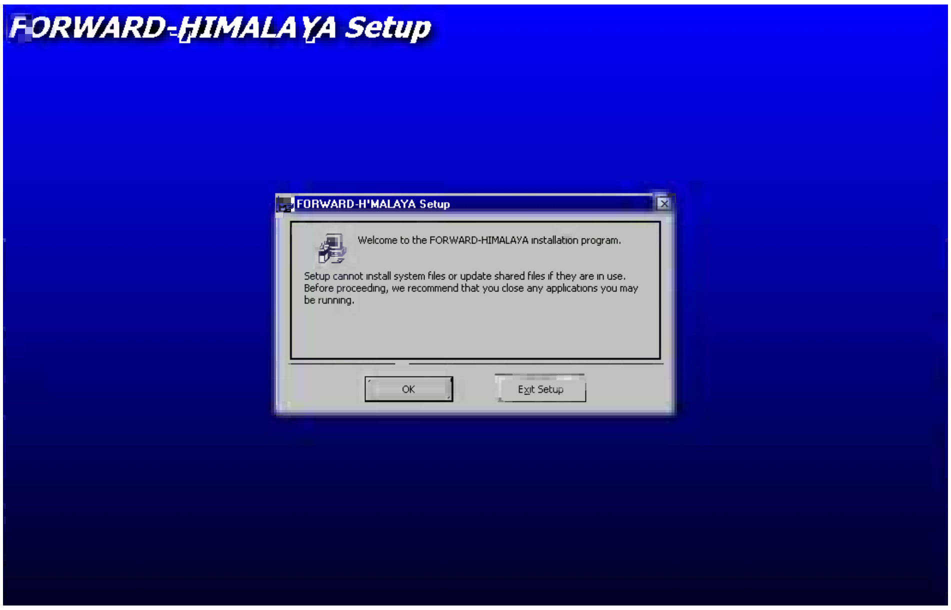
Software Installation

To install the Forward-Himalaya software:

1. Run the Setup.exe executable file supplied on the software CD ROM. 
2. Allow the setup files to be installed.

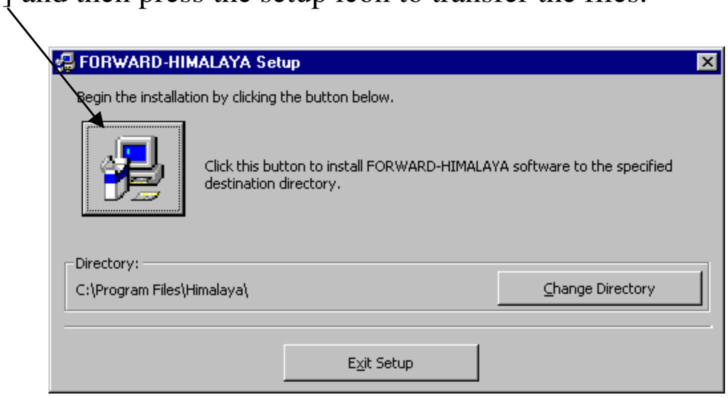


3. It may be required to restart the computer several times during this process. If a restart is needed, run the Setup.exe executable again.
4. Once all of the files have been copied, the main Setup Window is displayed.

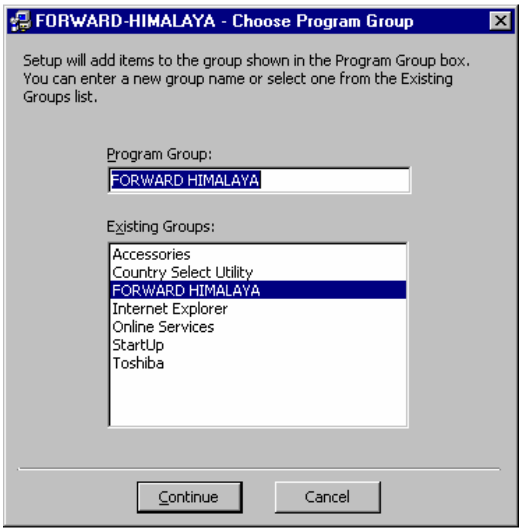


5. Close all other applications and press [OK].

6. Specify the destination directory for the application by Selecting [Change Directory] and then press the setup icon to transfer the files.



7. A shortcut to launch the application will be added to the Windows Start Menu. This shortcut can be added to existing program groups (e.g. **Accessories**), or a new program group can be created (e.g**. Forward-Himalaya**).



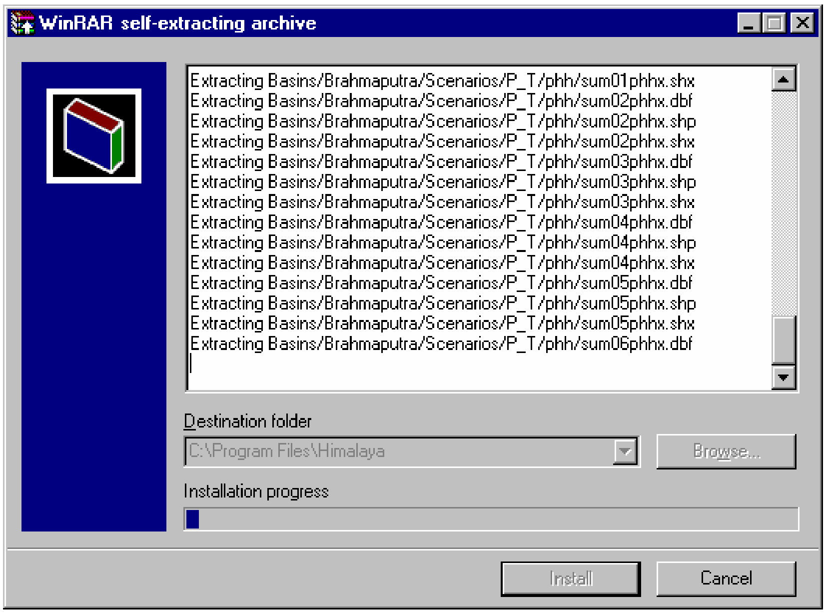
8. The main software application files will now install using the information obtained in the above steps. The setup procedure is completed when the following message is displayed:

Dataset Installation

Now that the main software application has been setup, the datasets required by the software must also be installed. To install the datasets for the application:

1. Run the Basins.exe executable file supplied on the software CD ROM.

2. Once the dataset installation software is displayed, specify the destination directory by selecting [Browse]
3. Select [Install] to transfer the required files.



Starting Forward-Himalaya for the first time

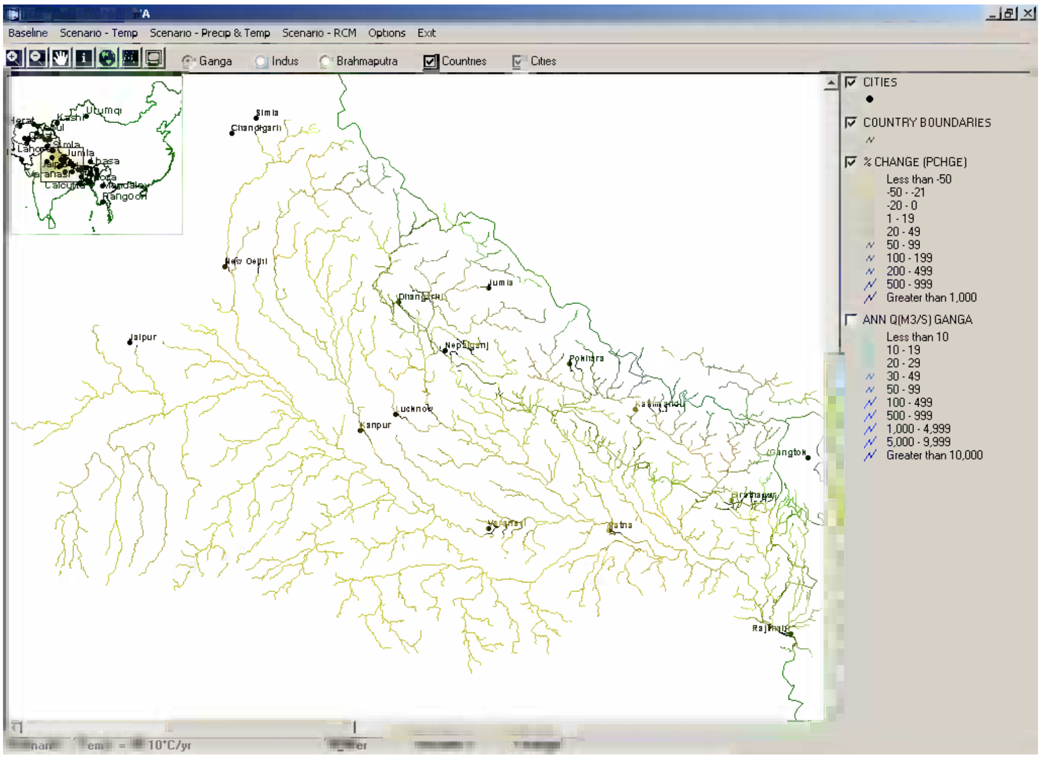
To start the Forward-Himalaya software, Select [Programs] from the Start menu and then select the installation directory followed by the executable file and icon. The User will then see the applications splash screen showing information about the software contributors.

The initial system information has not been specified and therefore the first launch of the application will fail. The User will be informed about this and then prompted to press [OK].

The **Main Window** is then displayed, but with most of the software functions disabled. To initialise the application select [Options] and then [Settings] from the pull-down menu. This will display the **Directory and File Settings** information. The user will need to enter the full directory path of the **Basin Directory** and make sure that the **Application Directory** and **Reference Table** paths are correct. The Reference Table is an MS Access database file holding information about the datasets. The file is called Ref_table.mdb and can usually be found in the application directory. The directory information can be entered by pressing the [Change] button. The directory information can be typed directly into the relevant text boxes or can be browsed in by using the buttons to the left of the text boxes [...] It's recommended that the User 'browses in' the path locations for all three settings even if the default locations look correct. Once the settings are entered onto the form, the User must press [Apply]. The application will have to be restarted for the changes to take effect. This is done by selecting [Exit] from the pull-down menu.

Main Window

When the User has launched the software application, the **Main Window** is displayed, as illustrated below. This window provides the primary Graphical User Interface (GUI) from which all functions can be accessed through a series of pull-down menus and/or icons.



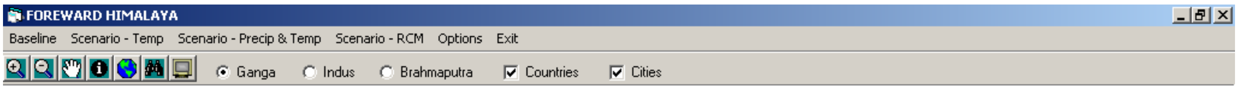
General Navigation Around the main window

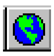
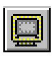
Operations from the Main Window can be accessed via the pull-down menus by moving the Mouse to the menu item and clicking with the left-hand Mouse button or using the hot keys (accessed by selecting ALT followed by the letter underlined) to select the required menu option. Alternatively, moving the mouse to the relevant icon provides a shortcut to the desired operation.

- The river network and all spatial data are displayed in the **Map Window.**
- The features which can be displayed within the Map Window are listed in the pull-down menus. Features can be selected for display by clicking on the appropriate **scenario** or **base map**. A list of active features in the Map Window can be obtained using the Legend icon in the tool bar. The Legend can be used to remove features from the Map Window by using the tick boxes.
- **Tool-tips** provide brief descriptive information on the icons in the tool bar. They appear when the cursor moves over the icon.
- **Scroll bars** will appear at the edge of the Map Window when the User views the river network in more detail and can be used to display different portions of the river network.
- The User may exit the Forward-Himalaya software system by selecting the [Exit].

Main Window Menus

The tool bar on the Main Window is shown below and a description of each of the menu options is described below.

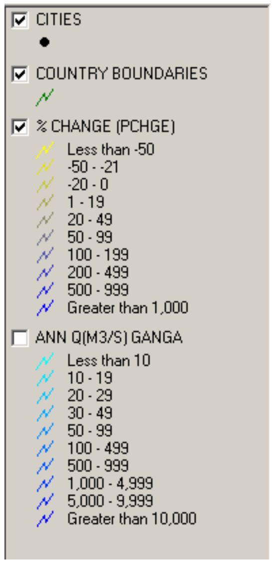


Menu	Menu Item or Sub-Menu	Icon	Description
[Base Maps]	Annual Winter Summer		Displays an annual, winter, or summer river network for the catchment selected on the toolbar. The rivers are colour coded according to discharge.
	Boundary		Displays the catchment boundary for the catchment selected on the toolbar.
[Scenario – Temp]	+0.03ºC/yr +0.06ºC/yr ….		Provides a method for comparing how flows would vary from decade to decade, relative to the baseline, by selecting different temperature increases.
[Scenario – Precip & Temp]	+0.2%P/yr_+0.06ºC/yr -0.2%P/yr_+0.06ºC/yr …..		Provides a method for comparing how flows would vary from decade to decade, relative to the baseline, by selecting different temperature increases and precipitation changes.
[Scenario – RCM]	Annual Winter Summer		Provides a method for comparing how flows would vary from decade to decade by selecting different outputs from the HadRM2 regional climate model.
[Options]	Zoom In		Allows the User to increase the resolution of the spatial data shown in the Map Window.
	Zoom Out		Allows the User to decrease the resolution of the spatial data shown in the Map Window.
	Pan		Allows the User to move around the map area by clicking and moving the mouse.
	Full Extent		Zooms out to display fully all layers on the map.
	Zoom Active Theme		Displays the currently active layer at its full extent.
	Tree View		Displays information about the available layers and file information about the active layers.
	Locator on/off		Display an **Inset Window** within the Main Window showing the map at its full extent whilst indicating the map extent of the current view.
	Settings		Provides a method of changing the directory and file settings
Exit			Exits the software

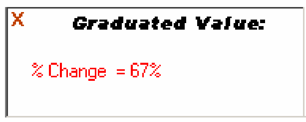
Before selecting a base map or scenario layer, the User is required to select the appropriate river basins. The User can chose between the Ganga, Indus, and Brahmaputra river basin by selecting the corresponding radio button on the toolbar.

Addition spatial information not specific to individual basins can also be selected from the tool bar. The User can choose to display both country boundary and city location information. This can be done by selecting the corresponding check boxes.

Managing the display of spatial data



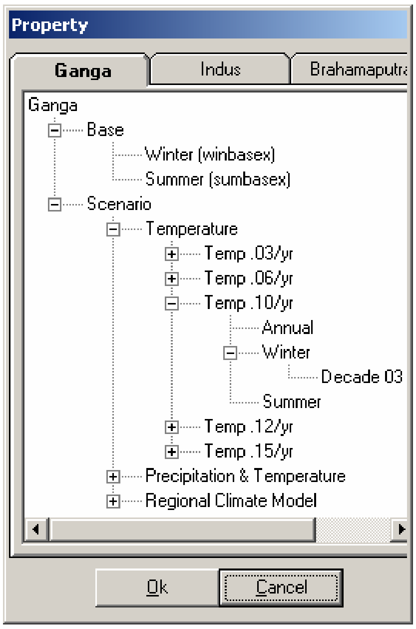
The software has a number of base maps for the User to display. The map layers available are river networks graduated by the river flow attribute for various periods, and also river basin boundaries. The User can select river networks showing the model result for different scenarios. These map layers are graduated using the change in flow (%) attribute. All of these layers can be selected using the dropdown menus. The legend for all layers can be seen on the right hand side of the Main Window. Layers can be turned on and off using the check box next to the appropriate layer or removed from the legend completely by a double left click with the mouse on the legend layer. Also the appearance order of the layers displayed on the Main Window can be altered by moving the order of the layer on the legend. The layer positioned at the top of the legend will be displayed on top of all the layers on the Main Window. Layers can be moved about on the legend by selecting and dragging them with the mouse.As mentioned above, other spatial information can be added to the map by selecting the required feature from the toolbar.



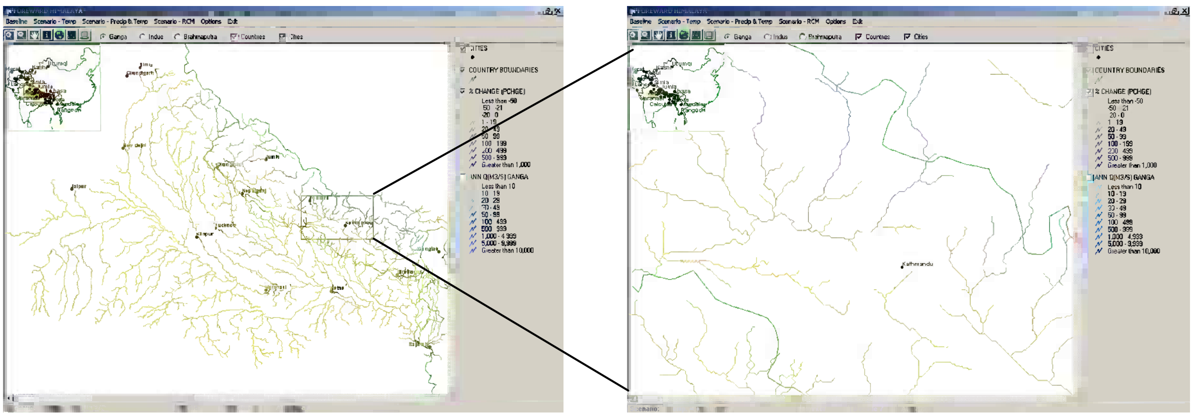
The information tool can be used to select a layer feature on the map window using the Mouse pointer. The User can display attribute information by selecting the information icon from the tool menu and then selecting the feature of interest. The attribute value will be displayed in the bottom left corner of the Main screen.

The **Status Bar** displayed on the Main Window below the map, shows information about the active scenario layer. This shows the chosen scenario, season, decade, and the active river basin name.

This information can also be viewed in the form of a tree structure diagram. The extended branches of the tree represent the active scenario and baseline layers. This is displayed by selecting [Options] and then [Tree View] or by selecting the icon on the tool bar. The Tabs at the top of the screen can be used to select the required catchment.



The zoom facility can be used by selecting the Zoom in tool from the tool bar and then by using the Mouse pointer to draw a rectangle on the map defining the new view extent.



To zoom out, the user can press the zoom out icon on the tool bar and then left-click on the map. Zoom out can also be achieved by using the zoom to full extent tool.