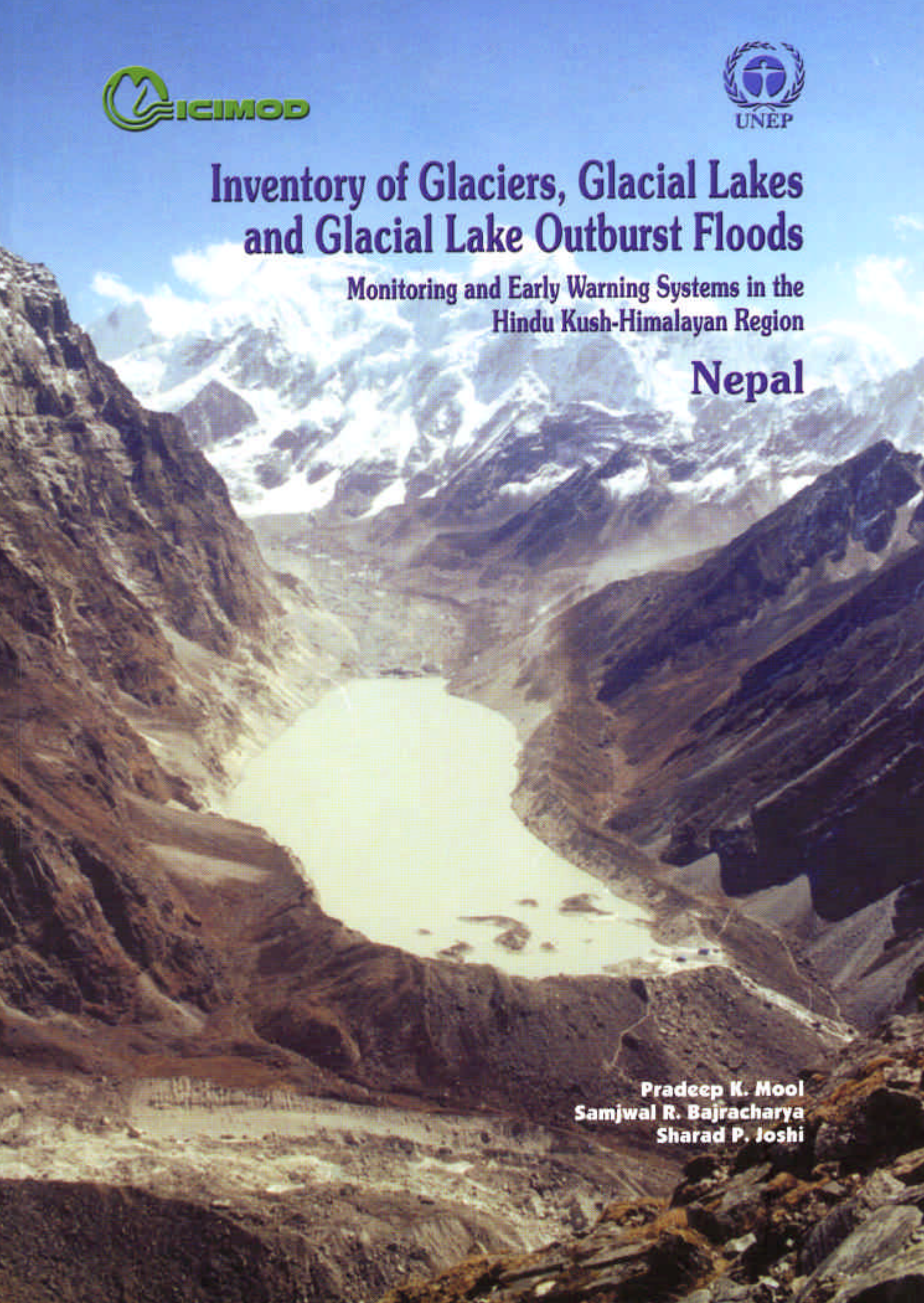

ICIMOD

UNEP

Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods

Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region

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In cooperation with
United Nations Environment Programme
Regional Resource Centre — Asia and the Pacific
(UNEP/RRC-AP)

International Centre for Integrated Mountain Development
Mountain Environment and Natural Resources' Information Systems
August 2001

Cover plate:

Front: Tsho Rolpa Glacial Lake, October 2000
— *Pradeep K. Mool*

Back plates:

Tsho Rolpa Glacial Lake Rolwaling Valley, Nepal

Top: Discharge from the recently constructed, gated canal has reduced the lake water level by three metres
— *Pradeep K. Mool*

Bottom clockwise:

View of the lake, June 1993
— *Pradeep K. Mool*

Glaciers (green) and lakes (blue) based on topographic maps published by the Survey of India (1960s–1970s) on a scale of 1:63,360 and draped over a digital elevation model (DEM) generated from the maps

Trakarding glacier, the source of the lake, October 1995

LANDSAT 4 TM image of 22 September 1992 draped over the DEM generated from the topographic map of the area

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Foreword

The glaciers of the Hindu Kush-Himalayas (HKH) are nature's renewable storehouse of fresh water from which hundreds of millions of people downstream benefit just when it is most needed – in the dry hot season before the monsoons. While the total number of glaciers in the region is still unknown, this study has for the first time documented that there are 3,252 glaciers in Nepal alone. Covering a large area of 5,324 square kilometres, these high frozen reservoirs release their water at the top of their watersheds. They serve as the perennial sources of the Ganges tributaries that wind their way through thousands of kilometres of grazing, agricultural, and forest lands and are used as renewable sources of irrigation, drinking water, energy, and industry.

However, these glaciers are retreating in the face of accelerating global warming. They are particularly vulnerable to climate change, and the resultant long-term loss of natural fresh water storage will have as yet uncalculated effects on communities downstream. More immediately, as glaciers retreat, glacial lakes form behind some of the now exposed terminal moraines. Rapid accumulation of water in glacial lakes, particularly in those adjacent to receding glaciers, can lead to a sudden breaching of the unstable 'dam' behind which they have formed. The resultant discharges of huge amounts of water and debris – a **glacial lake outburst flood** or **GLOF** – often have catastrophic effects downstream.

Many glacial lakes are known to have formed in the HKH in the last half century and a number of GLOFs have been reported in the region, including in Nepal in the last few decades. These GLOFs have resulted in many deaths, as well as the destruction of houses, bridges, fields, forests and roads. The lakes at risk, however, are situated in remote and inaccessible areas. When they burst, the local communities may have been devastated, while those in far away cities were largely unaware of the event.

In Nepal, this lack of awareness changed dramatically in 1985 following the catastrophic Dig Tsho glacial lake flood in 1985. As described in this publication, this lake high in the valley next to Mt. Everest, caused some deaths, wiped out 14 bridges, and swept away the newly constructed small hydel project in which US$ 1.5 million had just been invested. Following this some other glacial lakes were identified - such as the Tsho Rolpa that threatens the much larger Khimti hydel project as well as the local communities - and efforts, also described in detail in this publication, have been undertaken to mitigate the chances of such lakes also coming down in a wall of water and rocks.

Despite numerous studies of individual cases, there is still no detailed inventory of glaciers and glacial lakes, of GLOF events or of potential GLOF sites, in the HKH region – let alone of their impact on downstream populations and investments. This publication, along with the sister publication on the glaciers and glacial lakes of Bhutan, is designed to begin filling this pressing need. The research upon which it is based started in 1999, when the United Nations Environment Programme Regional Resource Centre for Asia and the Pacific (UNEP/RRC-AP) provided ICIMOD with the opportunity of using its expertise in the area of geographic information systems (GIS) to create a comprehensive inventory and GIS database of glaciers and glacial lakes in Nepal and Bhutan using available maps, satellite images, aerial photographs, reports, and field data on different scales. It built on ICIMOD's experience and long-standing concern with collecting and distributing material on the means to identify and mitigate mountain disasters and safeguard the livelihoods of vulnerable mountain people and their downstream neighbours.

One of the study's major objectives was to identify areas where GLOF events had occurred and lakes that could pose a potential threat of a GLOF in the near future. Out of a surprisingly large total of 2,323 glacial lakes, the researchers found 20 lakes that are potentially dangerous, including 17 that appear not to have experienced a prior GLOF. These results thus provide the basis for development of a monitoring and early warning system and for the planning and prioritisation of disaster mitigation efforts that could save many lives and properties situated downstream, as well as guide

infrastructure planning. In addition, it is anticipated that this study will provide useful information for many of those concerned with water resources and land-use planning.

As a presentation of the first results of the UNEP/RRC-AP supported study, this publication also includes a description of the methods used to identify glaciers, glacial lakes, and glacial lakes that may pose a threat; as well as an inventory (and maps) of the glaciers and glacial lakes in Nepal. It includes a summary of the results of studies of various glacial lakes, and a brief review of the causes and effects of known GLOF events in Nepal. The database and analysis are the first to cover the whole of the country on a large scale.

We are thus confident that this comprehensive report and digital database will be of service to scientists, planners, and decision-makers in many areas. Through their informed actions, we hope it will contribute to improving the lives of those living in the mountains, and help safeguard future investments for the benefit of many people in the region.

ICIMOD is grateful to UNEP/RRC-AP for its support to this work and the strong support and advice given while carrying out the project. We are also pleased that this project has enabled us to continue to strengthen our collaboration with the Government of Nepal's Department of Hydrology and Meteorology and to continue to assist in developing regional capacity and co-operation.

J. Gabriel Campbell
Director General
ICIMOD

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We thank Dr. Arun Shrestha and Dr. Birbal Rana of the Department of Hydrology and Meteorology of HMG/Nepal for their assistance in drafting parts of the report on the hydrological, glaciological, and GLOF mitigation studies for Nepal, and Dr. Hari Man Shrestha, the former executive secretary of WECS, who carried out a technical review of the study. We are also grateful to Dr. V. Galay and Dr. M. Zimmerman for their valuable comments and suggestions on the draft report. Mr. Basanta Shrestha, Acting Head, MENRIS, coordinated and made valuable inputs to the study. Other ICIMOD staff members who have assisted in the study include Ms. Monica Moktan, Ms. Rajani Bajracharya, Prof. Li Tianchi, Mr. Sushil Pradhan, Mr. Birendra Bajracharya, Mr. Sushil Pandey, Mr. Saisab Pradhan, Mr. Anirudra M. Shrestha, and Mr. Govinda Joshi. We would like to thank them all for their contributions. We would also like to thank Mr. Dharma Ratna Maharjan for the layout design and Mr. Asha Kaji Thaku for cartographic work. Mr. Pramod Pradhan, former Head of the MENRIS division of ICIMOD, is thanked for his valuable inputs and for coordinating the project process. Last but not least we wish to thank Mr. Surendra Shrestha, Regional Coordinator, Mr. Dola Govinda Pradhan, Dr. Chandra Giri, Mr. Mylvakanam Iyngararasan, Ms. May Ann E. Mamicpic, and Ms. Kritiya Gajesani of UNEP/RRC-AP for their timely and strong support and advice while implementing the project.

The terms glacier lake and glacial lake are often used interchangeably to refer to any lake associated with a glacier, regardless of the means of formation, although some investigators restrict their definitions to particular types of lake. For the purposes of this document, all lakes in contact with or near a glacier, or formed by recent glacial morphology, are referred to as 'glacial lakes'. In practice, most are of the type produced on a glacier's perimeter by meltwater from the glacier, by many termed a 'proglacial lake'.

The terms 'Himalaya' and 'Himalayas' are use to refer to the geological formation and the geographical region, respectively.

Acronyms

ADB	Asian Development Bank
AP	aerial photograph
AVNIR M	Advance Visible and Near Infrared Radiometer Multispectral
BPC	Butwal Power Company
CBS	Central Bureau of Statistics
CD	compact disk
CIDA	Canadian International Development Agency
DEM	digital elevation model
DHM	Department of Hydrology and Meteorology
DIHM	Department of Irrigation, Hydrology and Meteorology
EAP-AP	Environment Assessment Programme – Asia Pacific (UNEP)
ELOS	Extended Line of Site
EMS	electromagnetic spectrum
ERTS	Earth Resources Technology Satellite
ESCAP	Economic and Social Commission for Asia and the Pacific
ETH	Swiss Federal Institute of Technology
FCC	false colour composite
FINNIDA	Finnish International Development Agency
FMDP	Forest Development Master Plan
GEN	Japanese Glaciological Expedition to Nepal
Gl	glacial lake
GIS	geographic information system
GLOF	glacial lake outburst flood
Gr	glacier
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Agency for Technical Cooperation)
HKH	Hindu Kush-Himalayas
HMG/N	His Majesty's Government of Nepal
HRV	High Resolution Visible (SPOT)
ICIMOD	International Centre for Integrated Mountain Development
ILWIS	Integrated Land and Water Information Systems
IR	infrared
IRS1C	Indian Remote Sensing Satellite series 1C
IRS1D	Indian Remote Sensing Satellite series 1D
ITC	International Institute for Aerospace Survey and Earth Sciences
ITCZ	Inter-tropical Convergence Zone
JERS	Japanese Earth Resources Satellite
JICA	Japan International Cooperation Agency
Landsat	Land Resources Satellite
LIGG	Lanzhou Institute of Glaciology and Geocryology
LISS	Linear Imaging and Self Scanning Sensor (IRS)

masl	metres above sea level
MBRWS	Meteor Burst Remote Warning System
MBT	Main Boundary Thrust
MCC	Meteor Communication Corporation
MCT	Main Central Thrust
MENRIS	Mountain Environment and Natural Resources' Information System
MESSR	Multispectral Electronic Self Scanning Radiometer
MFT	Main Frontal Thrust
MOS	Marine Observation Satellite
MSS	Multi Spectral Scanner (Landsat)
NEA	Nepal Electricity Authority
NKAVH	Nepal-Kartenwerk der Arbeitsgemeinschaft für vergleichende Hochgebirgsforschung
NMS	Nepal Meteorological Service
NRSA	National Remote Sensing Agency
PAN	Panchromatic Mode Sensor System (SPOT)
RRC	Regional Resource Centre
RGB	red green blue
RS	remote sensing
SGHP	Snow and Glacier Hydrology Project
SGHU	Snow and Glacier Hydrology Unit
SPOT	Système Probatoire d'Observation de la Terre / Satellite Pour l'Observation de la Terre
SWIR	Short Wave Infra Red (JERS)
TM	Thematic Mapper (Landsat)
TTS	Temporary Technical Secretary
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
VNIR	Visible and Near Infra Red instrument
WECS	Water and Energy Commission Secretariat
WERDEP	Water and Energy Resources Development Project
WGI	World Glacier Inventory
WGMS	World Glacier Monitoring Service
WIDP	WECS Institutional Development Project
WISP	WECS/ NEA Institutional Support Project
WMO	World Meteorological Organisation
WWW	World Wide Web
XS	Multispectral Mode Sensor System (SPOT)

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