Andean-Asian Mountains Global Knowledge Exchange

On Glaciers, Glacial Lakes, Water & Hazard Management

An **Adaptation**Partnership Workshop

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Field Expedition to Imja Glacial Lake
September 3-24

Knowledge Sharing Workshop
September 25-26

Writer's Workshop
September 27-28

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Dedicated to the memory of

Robert E. Rhoades, Ph.D.

January 30, 1942 - March 24, 2010

Robert E. Rhoades, 'Bob' to his friends, was a mountain anthropologist, visionary, and inspiration to hundreds of people in the field of mountain studies that he helped create. He began his career in the mountains of Nepal in the 1960s, pioneering and mastering the field of 'Montology,' or study of mountain cultures and environments, that was followed by work for over a decade in the Andes of Peru. Bob shared his passion and ideas with his friends, professional colleagues, and students from 1991 until his death as Professor of Anthropology at the University of Georgia, Athens. Mountains were always at the heart of his interests, and he was particularly concerned about the rapid disappearance of the world's glaciers and the meaning of this loss to the identity of mountain people and cultures. Bob served as PI on the 2009 "Adapting to a World without Glaciers" workshop in Peru where the concept of an interdisciplinary, 'South-South' glacial lake expedition to Nepal was born. In spite of a growing and severe illness, Bob worked hard and for as long as he could to make the Imja Lake expedition a reality, signing each one of his notes with a cheerful "*for the mountains*" that will resonate forever in all of our hearts.

I. Project Summary

Members of the 2011 Imja Glacial Lake Expedition stand before the towering wall of Lhotse Shar (8386 m). As many of the larger glaciers have melted in the Hindu Kush-Himalaya (HKH) and Andes as a result of climate change, hundreds of new glacier lakes, holding millions of cubic meters of water, have been created. Usually contained by dams of loose boulders and soil, these lakes present a risk of glacial lake outburst floods (GLOFs). GLOFs unleash stored lake water, often causing enormous devastation downstream that can include high death tolls as well as the destruction of valuable farmland and costly infrastructure (e.g., hydroelectric facilities, roads, and bridges).

In July 2009, The Mountain Institute (TMI), in cooperation with the National Science Foundation, USAID, IRG, and other partners, convened an eight-day *Adapting to a World without Glaciers – Realities, Challenges, and Actions* workshop in Lima and Huaraz, Peru. Workshop participants consisted of Peruvian researchers and policymakers, and was also well represented by international researchers from other Andean countries, the United States, and Nepal. During the workshop, participants expressed keen interest in conducting a follow-on glacier conference in the Hindu Kush-Himalaya (HKH) region. The HKH conference would be designed to replicate and expand upon the Peruvian work in another glacial region of the world, resulting in important contributions to the growing body of knowledge related to climate change impacts while promoting South-South collaboration and exchange.

In response, The Mountain Institute and its partners hosted a unique series of on-site workshops in Sagarmatha (Everest) National Park and Kathmandu, Nepal from September 5 to 28, 2011, which convened more than 35 high altitude professionals from 15 different countries. The "2011 Andean-Asian Glacial Lake Expedition" was made up of physical and social scientists from the Andes, Hindu Kush-Himalaya, Central Asia, Japan, North America, and Europe, who spent 18 days in a remote region of eastern Nepal. With the active participation of local people – the first time in the 30-year history of research at Imja Lake – they discovered what appeared to be new, potential triggers to a glacial lake outburst flood that had gone unnoticed by previous studies. Ideas for new, practical solutions to the growing threat of GLOFs were discussed in detail, with an emphasis on the involvement of local people in all phases of future applied research, risk assessments, and, ultimately, remedial solutions.

The unique on-site field expedition was followed by a four-day workshop from September 25-28, 2011 in Kathmandu, hosted by the International Centre for Integrated Mountain Development (ICIMOD). There, expedition members were joined by additional physical and social scientists from the Hindu Kush-Himalayan region for an innovative series of presentations and exchange of experiences, followed by a "Writers Workshop" where priority recommendations for next steps and action were captured.

The expedition live-blogged the entire journey on a daily basis, with photos, videos, and events as they happened, which can be seen at http://www.mountain.org/blog/.

Additional links include:

Expedition Video
http://www.youtube.com/watch?v=v31d1jNPipg

Twitter
http://twitter.com/#!/TheMountainInst

Facebook
http://facebook.com/TheMountainInstitute

Please see Annex A for a complete "Media Scrapbook" of press releases and other awareness building outputs generated by the expedition.

Supporters of the Imja expedition and follow-on Kathmandu workshops include the U.S. National Science Foundation, U.S. Agency for International Development, U.S. State Department, Arkay Foundation, and UNDP/Nepal.

Julio Postigo and Alejo Cochachin study the Everest region map at basecamp next to Imja glacial lake.

Goals and Objectives

The primary goal of the field expedition and follow-on workshops was to catalyze, facilitate, and accelerate interdisciplinary exchange and collaboration among scientists, practitioners, and policy makers from the Andes, HKH, and Central Asia. Objectives of the initiative included the following:

1. Improved understanding and exchange of knowledge on the similarities and differences between climate change impacts within the HKH, Andes, and Central Asian regions, with a focus on the involvement of local people in all future research and pilot project activities
2. Enhanced engagement and linkages between research entities, partner institutions, and local communities for future collaboration and exchange of experiences
3. Prioritization of research and action projects in the areas of glacial recession, new glacial lake development, and future water supplies, and the development of concrete follow-up research and pilot project ideas and projects that can be submitted to donors and other funding partners
4. Establishment of a platform to continue the exchange of information set within the parameters of the workshop objectives.

Structure

1. Expedition-style field phase "HKH, Andean, and Central Asian Knowledge Exchange and Collaboration Workshop," (September 3-24). This was a small, expedition-style "mobile workshop" to the Imja Lake in Sagarmatha National Park (SNP) that consisted of Andean, Central Asian, HKH, European, and U.S. physical and social scientists, organized and led by TMI.
2. Kathmandu-based workshop "An Adaptation Partnership Workshop: Andean-Asian Mountains Global Knowledge Exchange On Glaciers, Glacial lakes, Water & Hazard Management," (September 25-26). A somewhat larger, Kathmandu-based workshop immediately followed the mobile workshop that allowed for a greater number of participants from the HKH region. Presentations on the physical and human dimensions of glacial recession, glacial lakes, and water supply were given by scientists from more than 16 mountain countries, and priority research and next steps identified by four separate break-out working groups.
3. The Writers Workshop (September 27-28) was aimed at capturing the experiences, lessons learned, and recommendations that emerged from both the Imja Lake field expedition and follow-up Kathmandu workshops.

Members of the Khumbu Alpine Conservation Project in Dingboche who welcomed the expedition members. Eight KACC members trekked to Imja Lake to assist with the scientist's assessments.

II. Priority Research and Action Projects

The High Mountain Glacial Watershed Program

Priority Research and Action Projects

The Global Glacial Mountain Partnership Community of Practice

3-28 September, 2011
Khumbu and Kathmandu, Nepal

Introduction: In July 2009, USAID and the National Science Foundation sponsored a workshop focused on climate change adaptation and glaciers – "Adapting to a World without Glaciers – Realities, Challenges, and Actions" that initiated the Global Glacial Lake Partnership concept. The eight-day workshop, held in Peru, was managed by the Mountain Institute (TMI) and local partners in Lima and Huaraz, and included Peruvian and other Andean researchers, graduate students, policy makers, and international researchers. At the end of the eight days, participants identified the need for a follow-on workshop in the Hindu Kush-Himalaya (HKH) region that would both advance contemporary understandings of climate change in the region and increase opportunities for exchange between Andean, Central Asian, and HKH practitioners. The HKH workshop – " An Adaptation Partnership Workshop: Andean-Asian Mountains Global Knowledge Exchange On Glaciers, Glacial Lakes, Water, and Hazard Management" was held in September 2011 and sought to share experiences with reducing the risks of glacier lake outburst floods (GLOFs) and risks associated with melting glaciers. The workshop was broken into three components: a three week "mobile workshop" trek to Imja Glacial Lake in the Mount Everest region; a two-day knowledge-sharing workshop; and a two-day writers workshop, where recommendations for priority research and action projects were captured. These recommendations are given below under the headings of Glacial Lake Management, Glacial Lake Research and Knowledge, and the Global Glacial Lake Partnership.

I. Enhancing Glacial Lake Management

Project 1: Develop and implement community-driven glacial lake management plans in several pilot sites (e.g., the Andes, the HKH and Central Asia)

Climate change is projected to warm high mountain areas by more than 4ºC by the end of the century. As a result, glacial lakes are forming, which present strategic opportunities for use as water storage reservoirs and hydropower generation, as well as hazards to downstream communities. This is a new phenomenon and an emerging issue about which little is known and few tools and institutional structures exist to deal with the problems. Dangerous glacial lakes will affect millions who rely on water currently stored in these glaciers. Hence, there is a need to develop and implement community-driven glacial lake management plans in several pilot sites. The proposed actions to achieve this include:

- Community network approach to glacial lake management: Undertake a participatory community process to: (1) identify local actors inside and outside the selected pilot region and community structures and how they relate to each other, and (2) work with communities to formulate a community network approach to glacial lake management.
- Assist communities to develop networks and new community organizational structures to deal with these issues: Create awareness and build capacity in communities through a network of effective villages, monitoring, and early warning networks, upstream-downstream networking, etc.
- Enhance communication among scientists, communities, and policy makers: Develop mechanisms for scientists, communities and policy makers to communicate and enhance the top-down – as well as bottom-up – flows of information, including documenting and using indigenous knowledge and social systems to improve glacial lake management.
- Develop and implement glacier lake management plans: Develop and implement a watershed-based community-driven glacier lake management plans for the selected pilot lakes (e.g., in the Andes, the HKH and Central Asia).
- Project monitoring, evaluation, and feedback: Develop a community-driven process of planning, evaluating, and monitoring of glacial lake management plans, including periodic revision and adaptation of the plans.
- A systematic way of assessing glacial lakes that informs glacial lake management decisions: Methods will be developed to capture and use available information, data, indigenous knowledge, and social systems to assess the level of risk posed by glacial lakes and embed this information into glacial lake management decision processes (e.g., to make decisions on what mitigation actions, if any, to take for a given glacial lake).
- Methods of determining and conveying risk and vulnerability: Downstream impacts of potential glacial lake outburst floods will be identified and modeled to determine the risk and vulnerability of communities and the impact on infrastructure, services and ecosystems.

Project 2: Reduce risk from glacial lakes and the vulnerability of effected high mountain communities, infrastructure, and environments

Employ the acquired knowledge to reduce the risk of the glacial lake and the vulnerability of related communities, infrastructure, and the environment. This could require a number of interventions, such as:

1. Engineering decisions
    a. Reduce lake volume
    b. Install pipes to limit the rise of water in the lake
    c. Restore or strengthen moraines damming the lake
2. Install early warning system
3. Involve the local communities
    a. Share information in multiple venues involving multiple stakeholders
    b. Build capacity of local community
    c. Involve local community in operating the process
4. Prepare emergency and evacuation plans
5. Prepare contingency plan for tourism

II. Enhancing Glacial Lake Research and Knowledge

Project 1: Assessing risk of glacial lakes and the vulnerability of related communities, infrastructure, and environment

The hazard probability resulting from glacial lakes should be assessed with a focus on the vulnerability of the affected communities in order to act upon and reduce the potential risks. These assessments require the gathering of data on: the lake as well as the people who will be impacted by a possible outburst flood.

Objectives:

Lake:

1. Study the zone of the triggering impact above the glacial lake
2. Study the characteristics of moraines and the glacial lake
3. Study the transit zone downstream of the glacial lake

People:

1. Map the affected and vulnerable communities
2. Conduct a demographic survey
3. Study socio-economic structures and cultural institutions

Physical:

1. Three-dimensional Lidar, Satellite, Airborne, Terrain imaging
2. Geophysical surveys (ground penetrating radar and electromagnetic) in cross-sections and longitude sections
3. Drilling and sampling
4. Permeability tests

Social:

1. Community mapping, census
2. Household surveys, interviews, life-histories, focus group discussions
3. Land and water organization

Project 2: Generate knowledge for assessing and reducing risk and vulnerability in other parts of the world

Once the vulnerability and the risk of glacial lakes have been reduced, it is crucial to share the experiences and knowledge in order to widen the benefits to concerned communities in other parts of the world. In order to generate and disseminate this knowledge, three different knowledge sectors have been identified:

1. General knowledge
    a. Trainings, teaching, course materials
    b. Develop easily accessible and understandable information for the public
    c. Networking of concerned individuals and institutions – community to community
2. Research
    a. Pooling data and creating an interactive database
    b. Inventory of glacial lakes

    c. Develop models
    d. Networking of concerned individuals and institutions – researchers to researchers
    e. Publications
3. Action
    a. Disaster (Glacial Lake) Management Plans
    b. Diffusion of information through various media including cell phones, radios, television etc.
    c. Networking of concerned individuals and institutions – community to researchers to community

Project 3: Create and compile a summary of reference documents and other information resources to serve the Global Glacial Mountain Partnership

The network of professionals representing the many disciplines who will participate in the Global Glacial Mountain Partnership (GGMP) will be well-served by having easy access to information resources that reflect the historical knowledge and current best practices for meeting glacial lake challenges. With centralized and regularly updated content available via a website, members of the GGLP can effectively share lessons learned, discuss protocols, build a body of knowledge about glacial lake dynamics, and avoid re-inventing the wheel at a time when threats are accelerating and risks of catastrophic accidents are increasing.

The proposed actions to achieve this include:

- Create and maintain an online repository of information that spans peer-reviewed research articles, conference proceedings, popular news articles and links, and discussion boards for members to access.
- Manage network contacts, reports dissemination, discussion boards, and periodically update overviews of lessons learned in evaluating glacial lakes.
- Collect, distribute, and translate (as necessary) available tools for engaging stakeholders in glacial lake assessments and project development.
- Synthesize and update a dynamic handbook of glacial lakes assessment and management approaches that includes comparative case studies, and provides support to projects to inventory, prioritize, and mitigate glacial lakes in GGLP members' countries.
- Support the GGLP through an active outreach effort that includes list serves, online conferences, blog hosting, and announcement of funding opportunities.

Global Glacial Lake Partnership

One of the four outcomes of the Writers Workshop was the establishment of a platform to continue the exchange of information set within the parameters of the workshop objectives. Participants set forth a list of characteristics and goals that will shape the establishment of the Global Glacial Lake Partnership Community of Practice (CoP). They include the following:

1. Overall Concept

The overall concept of the community of practice is to:

- Foster and promote adaptation actions by connecting practitioners and supporting the transfer of knowledge
- Connect with those who are most directly impacted by the effects of climate change on glaciers and glacial lakes

- Scale up actions and share information that is often implemented or known only in highly decentralized contexts

2. Objectives and Purpose of Proposed Initiative

The objectives of the proposed Glacial Lake Partnership CoP are to improve understanding and facilitate the exchange of knowledge between researchers, practitioners, and planners on the similarities and difference between the HKH, Andes, and Central Asian regions.

3. Expected Benefits of the CoP

Benefits to members

- Build and foster relationships (researcher-to-researcher; community-to-community)
- Provide virtual and face-to-face opportunities for members to exchange experiences, methods, and research
- Serve as an information clearing house and provide on-demand access to knowledge (case studies, research, etc.)
- Produce policy briefs, guidance, handbooks, and tools
- Reduce risk of duplication and improve prospects for collaboration, synergy, and innovation
- Facilitate exchange between regions, countries, and hemispheres
- Foster collaboration with donor-led regional and global initiatives

Contributions to glacial lake management

- Establish and promote standards and best practices for communicating with glacial lake communities
- Identify concrete research and pilot development topics
- Support research on and documentation of indigenous knowledge of glaciers, glacial lakes, and high mountain features
- Conduct external communication to promote public awareness of the issues and publicize success stories
- Translate science for decision makers and stakeholders
- Mentor and support young scientists, and train a new generation of experts

4. Proposed Membership of CoP

Practitioners and Researchers

- Physical scientists
- Glaciologists
- Socio-economic researchers
- Glacial Lake Managers
- Hydrologists
- Engineers
- Students

Universities

- Ohio State

- UCSC
- University of Texas
- University of Copenhagen
- University of Hokkaido
- University of Colorado at Boulder
- Tribhuvan University/Nepal

Non-Governmental Organizations

- The Mountain Institute
- ICIMOD
- Bolivian Mountain Institute
- WWF
- Institute for Social and Environmental Transition (ISET) Nepal
- Nepal Mountaineering Association
- International Mountaineering and Climbing Federation (UIAA)

Government Agencies and Institutes

- Peruvian Glaciological and Hydrological Resources Unit
- Geological Survey of Bhutan
- Global Change Impact Study Center – Pakistan
- Pakistan Meteorological Agency
- Kyrgyz Academy of Science
- Tajikistan State Agency for Hydrometeorology
- Department of Hydrology and Meteorology – Nepal

Donor Agencies

- USAID and Department of State
- UNDP-USAID/Nepal
- NSF
- UNDP
- World Bank
- DFID
- Turner Foundation
- National Geographic Society

5. Focus of the CoP

- Water and hazard management
- Sustainable livelihoods
- International and regional cooperation

6. Proposed Strategy for Building the Global Glacial Lake Partnership

- Phase 1: Define member needs, identify core CoP membership and facilitation team, and identify website platform and location
    - Vet and confirm CoP concept, goals, and objectives, and target audience
    - Survey potential members to gauge interest, where people currently obtain information, what information people are looking for, what activities people will participate in, what services members would benefit from, what individuals and organizations can contribute
    - Identify Facilitation Team and Core Resource Group members
- Phase 2: Implement CoP platform
    - Design and implement taxonomy, architecture, functionality, user roles, and "look and feel"
    - Collect and upload content; test functionality
    - Develop monitoring and evaluation plan
    - Develop membership rules/norms of behavior and membership form
    - Launch platform at face-to-face event and register members
- Phase 3: Build and Grow CoP
    - Roll-out CoP activities and services
    - Grow and expand membership
    - Monitor, evaluate, and implement changes as needed

Host and Facilitator for the CoP

- Initial host: USAID GCC Project
- Proposed facilitator:

Structure of the CoP

The CoP is both an in-person and online network. The CoP will support workshops and meetings for the membership as well as publicize and participate in events that may be of interest to members. In between meetings, members will be connected through an email listserv and an online space for community interaction.

The CoP will consist of the following:

- Core Resource Group: A group of members invited to provide technical guidance to the Facilitation Team and the CoP, support CoP online and face-to-face activities (e.g. serve as moderators), and champion the CoP among their professional networks
- Facilitation Team: A two-member team composed of a research assistant and a facilitation expert who manages CoP activities, services, and membership
- Members: Practitioners

Services, Resources, and Activities of the CoP

Members will be invited to face-to-face meetings held at least once or twice a year where they can renew their ties with other members, share their best practices, demonstrate their tools/approaches, promote their work, seek peer support, learn from others, find opportunities to collaborate to advance the field, etc.

In between face-to-face meetings, members have the option to participate through email (listserv) or online (through virtual forums). Key services and resources to online community members could include the following:

- Post queries: Members can post questions to the community, and will receive responses as they come in from other members as well as a consolidated reply produced by the facilitation team. The consolidated reply may include additional research conducted by the facilitation team.
- Participate in or initiate discussions: Members can participate in, propose, or guest-moderate discussions. At the end of the discussion period, members receive a synthesis of the discussion.
- Consult with the community: Members can post an idea or draft of a document, such as a project, program or policy paper, to solicit input from the community.
- Receive Electronic Community Newsletter: Produced for and circulated widely to the community to feature news, updates, case studies, stories from the field, best practices, tools, etc.
- Access Best Practice Funds: Members can apply for limited seed funds to replicate or scale up a best practice.
- Access Joint Innovation Funds: Members can apply for limited seed funds for an initiative that will be undertaken jointly by two or more members of the CoP (from different organizations/institutions) and that will contribute new knowledge (in the form of tool, guidance note, approaches, etc.) to the wider community.

Other activities of the online CoP may also include:

- Webcasts of events related to the community.
- Webinars on priority topics/issues for community members led by a subject matter expert or how to apply a particular tool or approach.
- Narratives and Story Telling can be of great use in capturing and disseminating technical subject matter expertise and on-the-ground application of concepts and ideas. Technical experts are interviewed and audio-recorded. Recordings can be posted online as a standalone audio file or attached to visual presentation (e.g. PowerPoint). The Facilitator could serve as the interviewer and draw out the experiences and knowledge most relevant to the CoP members.

III. Papers

An Introduction: Enhancing the Control and Management of Dangerous Glacial Lakes through Himalayan-Andean Exchange and Collaboration

Alton C. Byers, Ph.D.
Director, Science and Exploration
The Mountain Institute

Introduction

Glacier-dominated mountains play a major role in providing water to large populations, especially in the Himalayas (Singh and Bengtsson, 2004; Barnett et al., 2005) and Andes regions (Bradley et al., 2006). Continued and increasing glacier melting may initially increase runoff in some regions, but lack of a glacial buffer ultimately will cause decreased reliability of dry season streamflow (Bradley et al., 2006), affecting water supply, agriculture, hydropower, and ecosystems. These glacial-dominated areas pose unique challenges to downstream communities in adapting to recent and continuing global climate change, including reduced dry season flows and increased threats of glacial lake floods, both of which have strong impacts on regional social, environmental, and economic systems.

As many of the larger glaciers have melted in the Hindu Kush-Himalaya (HKH) and Andes, hundreds of new glacier lakes, holding millions of cubic meters of water, have been created. Usually contained by dams of loose boulders and soil, these lakes present a risk of glacial lake outburst floods (GLOF). Triggering factors for GLOFs include: "…lake area expansion rate; up-glacier and down-valley expansion rate; dead-ice melting; seepage; lake water level change; and surge wave by rockfall and/or slide and ice calving" (Watanabe et al. 2009). GLOFs unleash stored lake water, often causing enormous devastation downstream that can include high death tolls, as well as the destruction of valuable farmland and costly infrastructure (e.g., hydroelectric facilities, roads, and bridges). However, in spite of the recent growth in international academic and media attention, relatively little is known about these lakes – their physical characteristics, danger level, prospective downstream impacts in the event of an outburst, and mitigation methods appropriate and applicable to remote regions within the Nepal Himalaya (see: Byers 2008).

The Cordillera Blanca in Peru, on the other hand, has a much longer and more tragic history of glacier-related catastrophes that has been recorded since 1725 (Carey 2009; 2010). By the mid-20th century, warming trends had caused the recession of hundreds of glaciers throughout the range, leaving behind a number of large glacial lakes perched above the regional agricultural and municipal hub of Huaraz, with a population of about 80,000 at that time.

In July 2009, The Mountain Institute (TMI), in cooperation with the National Science Foundation, USAID, IRG, and other partners, convened an eight-day *Adapting to a World without Glaciers – Realities, Challenges, and Actions* workshop in Lima and Huaraz, Peru. Workshop participants consisted of Peruvian researchers and policymakers, and was also well represented by international researchers from other

Andean countries, the United States, and Nepal. During the workshop, participants expressed keen interest in conducting a follow-on glacier conference in the Hindu Kush-Himalaya region. The HKH conference would be designed to replicate and expand upon the Peruvian work in another glacial region of the world, resulting in important contributions to the growing body of knowledge related to climate change impacts while promoting South-South collaboration and exchange.

In response, The Mountain Institute and partners hosted a unique series of on-site workshops in Sagarmatha (Mount Everest) National Park and Kathmandu, Nepal from September5 – 28, 2011 that convened more than 35 high altitude professionals from 15 different countries. The "2011 Andean-Asian Glacial Lake Expedition" was made up of physical and social scientists from the Andes, HKH, Central Asia, Japan, North America, and Europe, who spent 18 days in a remote region of eastern Nepal. With the active participation of local people – the first time in the 30-year history of research at Imja

Lake – they discovered what appeared to be new, potential triggers to a glacial lake outburst flood that had gone unnoticed by previous studies. Ideas for new, practical solutions to the growing threat of GLOFs were discussed in detail, with an emphasis on the involvement of local people in all phases of future applied research, risk assessments, and, ultimately, remedial solutions.

The unique on-site field expedition was followed by a four-day workshop from September 25 – 28, 2011 in Kathmandu, hosted by the International Centre for Integrated Mountain Development (ICIMOD). There, expedition members were joined by additional physical and social scientists from the Hindu Kush-Himalayan region for an innovative series of presentations and exchange of experiences, followed by a "Writers Workshop" where priority recommendations for next steps and action were captured.

The overall purpose of the on-site and conference hall workshops was to strengthen linkages and partnerships between South-South practitioners, researchers, and policy makers in ways that can facilitate glacial lake hazard reduction while advancing our understanding of glacial retreat impacts on present and future water supplies. Collectively, the initiative was distinguished from other conferences by its (a) involvement of world-class glacial lake outburst flood specialists from Peru, Central Asia, the HKH region, Japan, Europe, and the United States, (b) focus on collaboration and exchange between Andean and Asian scientists, practitioners, graduate students, and policy makers, and (c) a mobile, "expedition-style" workshop approach, where participants actually trekked to and directly assessed, with the participation of local people, the potentially dangerous Imja Lake in Nepal's Sagarmatha (Mount Everest) National Park. The unique "mobile workshop" approach seems to have assured that field-based exchanges of direct experiences in glacial lake control and management would and did take place, actively incorporating the insights and suggestions of local Sherpa people in meetings and presentations. This was one of the first workshops of its kind to take place in the field, confronting real problems and developing prospective solutions with the assistance of local stakeholders. Outputs included (a) a handbook on 50 years of glacial lake control and management techniques, (b) expedition and workshop proceedings, (c) a documentary film and other media/dissemination outputs about climate change, the workshop, and South-South collaboration in exchange, and (c) strategic plans for continued and accelerated collaboration and exchange through the initiation of a "Global Glacial Lake Partnership" (GGLP).

The Global Glacial Lake Partnership is dedicated to the increased understanding of new glacial lakes, contemporary and future water supplies, and participation of local people in all future research, action plan, and mitigation activities. Under the GGLP, online platforms and discussions will be developed that share research, support young scientists, develop a calendar of upcoming activities, disseminate funding opportunities, announce new workshops and related events, and serve as a clearinghouse for research and case studies. Publications will include policy briefs, frameworks for glacial lake assessment and community involvement, and handbooks for glacial lake control and management (in press). The partnership will actively foster researcher-to-researcher, community-to-community, and researcher-to-community exchanges, while fostering collaboration with donor-led, global and regional initiatives (e.g. the Inter-ministerial Nepali Government Mountain Initiative). Members would include a range of universities, research organizations, donors, governments, and local communities. Further details are provided in the full expedition and workshop proceedings.

But perhaps the most significant and pioneering achievement of the Imja Lake expedition was its involvement of local people in both debriefing meetings as well as on-site study visits. Local people voiced a strong objection to the numerous foreign and national researchers who had been studying the

Imja Lake for over 30 years, and who had never once shared their information and results with the community. It quickly became apparent, however, that they were among the most informed people around in terms of knowledge of the lake's growth rates, as well as of a disturbing number of potential GLOF "triggers" that had gone unnoticed by scientists studying the region only two years before. These included new crevasses in the debris-covered terminal moraine, indicating the ice core nature of the moraine that may be undergoing rapid ablation processes; the growth, merging, and expansion of small meltwater ponds that could turn much of the remaining terminal moraine into a lake within the near future; water seepage at the exterior base of the terminal moraine that may indicate further morainal instability; and, of course, the huge volume (35 million m^3) of water contained within the lake itself.

As one of the expedition participants said during discussions with local people at the lake, what is clearly needed now is an action plan. But contrary to the negative reputation that research and researchers had attained over the years, such an action plan would, by necessity, include priority, participatory research in its design so that both scientists and local people could arrive at the best understanding of exactly what was happening to the lake, when it was likely to be dangerous, and what the range of options for adapting and/or mitigating the potential threats might be. These options might include: (a) no action, accepting the risk of a possible GLOF at some unknown point in the future; (b) relocating lodges and other structures to higher elevations to avoid any potential flood damage; or (c) implementation of an engineering solution, such as siphoning or controlled drainage canals. Regardless of the option selected, it became clear to all expedition members that the ultimate course of action must be based on the decisions of local communities and people, and not of governments, donors, or other external agencies.

The following papers, authored by expedition and workshop participants, contain a wealth of experience from the physical and social sciences alike, experience that can help us to better understand and cope with the new and growing threat of GLOFs in the world's high mountain regions. The papers also discuss insights gained regarding recent climate change impacts on glaciers, the formation of glacial lakes, water supply, and ecosystems within the world's highest mountains. Each author has had years of experience conducting field work in these high and remote mountain regions, and come from a diversity of countries that include Bhutan, Bolivia, China, Denmark, Germany, India, Japan, Kyrgyzstan, Nepal, Pakistan, Peru, Tajikistan, Uzbekistan, and the United States.

During the course of the three-week field expedition to Imja Glacial Lake and the follow-on workshops in Kathmandu, dozens of new and synergistic friendships, partnerships, and new research projects were formed between participants. It is to be hoped that the Andean-Asian Collaboration and Exchange Workshop will be the first of many more to come.

References:

Barnett, T.P., J.C. Adam and D.P. Lettenmaier. 2005. Potential impacts of a warming climate on water availability in snow dominated regions. *Nature*, 438(7066), 303–309.

Bradley, R.S., M. Vuille, H.F. Diaz and W. Vergara. 2006. Threats to water supply in the tropical Andes. *Science* 312(5781), 1755–1756.

Byers, A.C. 2008. An assessment of contemporary glacier fluctuations in Nepal's Khumbu Himal using repeat photography. *Himalayan Journal of Sciences* Vol. 4, No. 6: 21-26.

Byers, A.C. 2010. The threat from above: a reconnaissance of new and dangerous glacial lakes in the Mt. Everest and Makalu-Barun National Parks, Nepal. Final report, Grant W67-09, National Geographic Society-Waitt Grant Program. Washington, DC: National Geographic Society.

Carey, M., 2005. Living and dying with glaciers: people's historical vulnerability to avalanches and outburst floods in Peru. *Global & Planetary Change* 47, 122-134.

Carey, M. 2010. *In the Shadow of Melting Glaciers: Climate Change and Andean Society*, Oxford Univ. Press, New York.

Eriksson, M., Xu, J., Shrestha, A.B., Vaidya, R.A., Nepal, S., Sandström, K. 2009. The Changing Himalayas – Impact of climate change on water resources and livelihoods in the greater Himalayas. ICIMOD 2009, ISBN 978 92 9115 1110.

Orlove, B., E. Wiegandt, et al., Eds. (2008). Darkening Peaks. Glacier Retreat, Science and Society. Berkeley, University of California Press.

Sherpa, S.I. 2009. Lodge owner and Chairman, Khumbu Alpine Conservation Committee, Dingboche, Nepal. Personal communication, November, 2009, Dingboche, Nepal.

Singh, P. and L. Bengtsson. 2004. Hydrological sensitivity of a large Himalayan basin to climate change. *Hydrol. Process.*, 18(13), 2363–2385.

The Mountain Institute 2009. From the Glaciers to the Coast: Building Climate Change Awareness and Resilience in the Ancash and Piura Watersheds of Northern Peru. Proposal and project planning documents prepared for the US Agency for International Development/ Peru Mission. Lima and Huaraz: The Mountain Institute.

US Agency for International Development 2007. Adapting to climate variability and change: a guidance manual for development planning. Washington, DC: USAID.

Glacial Lakes of the Hinku and Hongu Valleys, Makalu-Barun National Park and Buffer Zone, Nepal

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Mountain areas are particularly vulnerable to the impact of climate change. Currently, global warming is changing the water storage functionality of snow and glaciers, as well as changing frequency, magnitude, and seasonality of rainfall. Individual glacier response to warming trends is increasingly recognized as being heterogeneous and subject to a range of variables that can include debris cover, altitude, aspect, (Kargel et al. 2011) and latitude (Armstrong 2010). However, as many of the larger glaciers have melted in the Himalayas and Andes, hundreds of new glacier lakes, holding millions of cubic meters of water, have been created. Usually contained by dams of loose boulders and soil, these lakes present a risk of glacial lake outburst floods (GLOF). Triggering factors for GLOFs include "…lake area expansion rate; up-glacier and down-valley expansion rate; dead-ice melting; seepage; lake water level change; and surge wave by rockfall and/or slide and ice calving" (Watanabe et al. 2009). GLOFs unleash stored lake water, often causing enormous devastation downstream that can include high death tolls as well as the destruction of valuable farmland and costly infrastructure (e.g., hydroelectric facilities, roads, and bridges). Examples include the 1941 GLOF disaster above Huaraz, Peru that killed nearly 6,000 people within minutes (Hambrey and Alean 2004; Carey 2005; Carey, 2010); the 1985 Langmoche outburst in the Sagarmatha (Mt. Everest) National Park, Nepal that destroyed the Thami hydroelectric facility, hundreds of hectares of cropland, and dozens of bridges downstream (Vuichard and Zimmerman 1986); and the 1998 outburst of the Sabai Tso in the Hinku valley, Makalu-Barun National Park, Nepal that destroyed trails and seasonal settlements for nearly 100 km downstream (Cox, 1999; Osti and Egashira 2009).

During the past several decades in the Mt. Everest and Makalu-Barun National Parks of Nepal, 24 new glacial lakes have formed and 34 major lakes have grown substantially as a result of climate change and regional warming trends (Bajracharya et al. 2007). Recent satellite analyses suggest that at least twelve (12) of the new or growing lakes within the Dudh Kosi watershed, nine of which are located in the remote Hinku and Hongu valleys of Makalu-Barun National Park, are "potentially dangerous" based on their rapid growth over the past several decades (Bajracharya et al. 2007; Xu et al. 2007; Bolch et al. 2008; Watanabe et al. 2009). Until recently, however, relatively little was known about these lakes, including their physical characteristics, danger level, prospective downstream impacts in the event of an outburst, and mitigation methods appropriate and applicable to remote regions within the Nepal Himalaya (see: Byers 2008). The following paper provides results of the two separate field expeditions to the Hongu valley conducted in October-November of 2009 and 2010.

Location: The Mera Peak region is located four days walk east of the Lukla airstrip in the Makalu-Barun National Park, Nepal (Figure 1). Vegetation within the park ranges from subtropical Sal (*Shorea robusta*) forests at elevations below 1,000 m; temperate zone oak/maple/magnolia forests between 2,000-3,000 m; birch/fir/rhododendron forests in the subalpine (3,000 m to 4,000 m); and the herbs, grasses, and rhododendron/juniper shrub of the alpine pastures (4,000-5,000 m) (Shrestha 1989; Taylor-Ide et al. 1992; Dunsmore 1988; Stainton 1972). Access is gained first by ascending the 4,600 m Chetra La pass, passing through the *goths* (yak and sheep herding huts) and tourist settlements of Thukdim, Chutanga, Karki Teng, and Chhetrala; descending through Chhetrawa to the subalpine rhododendron/ birch/fir forests of the Hinku Khola; then proceeding north up-valley to the pastures and settlements of the alpine zone (>4,000 m) and villages of Kothe, Tagnag, and Khare (see: Byers, forthcoming). The Hongu valley is reached by crossing the Mera La (5,400 m). To reach the Hongu valley, one descends to Kungma Dingma (4,785 m), a small rock hut used by shepherds with a new lodge/restaurant under construction in 2009, a response to the growing popularity of the Mera Peak-Mera La-Amphu Laptsa-Island Peak climb and circuit. Exit from the valley is either to the north and over the 5,800 m Amphu Laptsa pass into the Sagarmatha (Mt. Everest) National Park, or south for a six- to eight-day trek through uninhabited alpine and sub-alpine ecosystems prior to reaching the village of Cheskam.

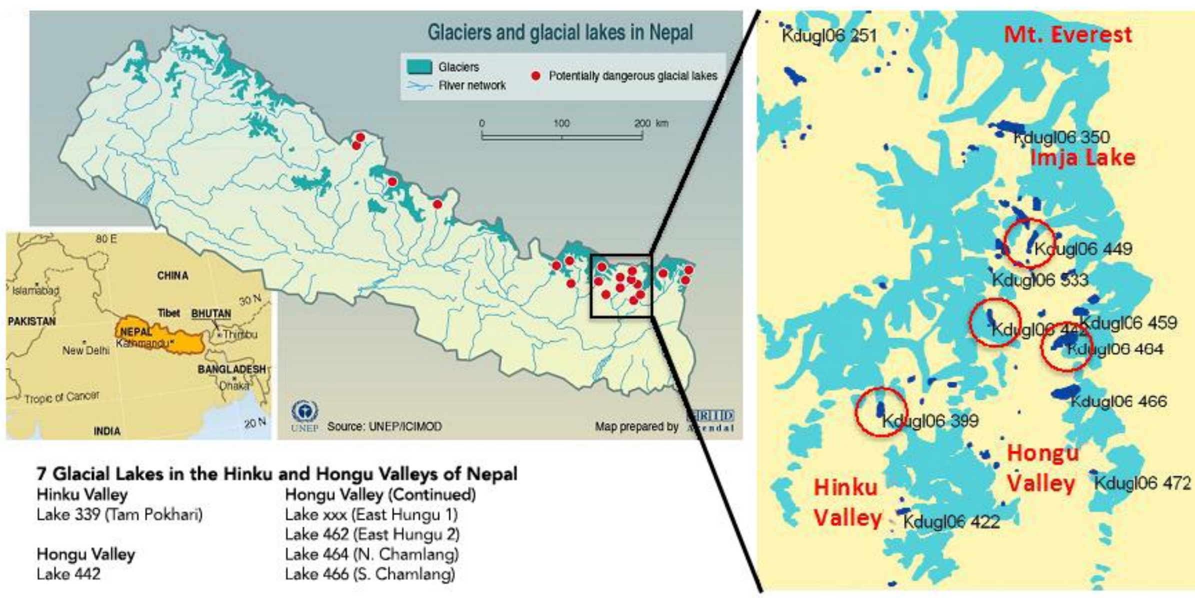

Figure 1. The Hongu Valley, Nepal showing potentially dangerous glacial lakes.

Glacial Lakes in the Hinku and Hongu Valleys: Table 1 shows the lake number, name, and altitude of the nine potentially dangerous lakes in the Hongu valley watershed as determined by Bajracharya et al. (2007:27). Considerable confusion regarding lake names was encountered; we therefore propose a more standardized system as shown in Table 1. "GLOF Risk" is shown both as reported in Bajracharya et al. (2007) and as determined by this study on the basis of observational factor ranking that included on-site observation of presence of overhanging ice, overhanging debris, unstable terminal moraine, terminal moraine geomorphology, and lake size and volume (see: Ives et al. 2010:8). Map 2 shows the locations of these lakes within the Hinku and Hongu sub-basins.

Table 1. Summary attributes of glacial lakes in the Hinku and Hongu valleys.

Lake ID	2007 Name	Proposed Name	Altitude (m)	Risk (Bajracharya et al. 2007)	Risk (this study)
Kdu_gl 399 (F)	Sabai Tsho	Tama Pokhari	4431	High	Low
Kdu_gl 422 (G)	Dudh Pokhari	Dudh Pokhari	4760	High	Low
Kdu_gl 442 (H)	Unnamed	Mera Glacier Lake	5266	High	Low
Kdu_gl 449 (J)	Hungu	Hungu	5181	High	Medium-High
Kdu_gl 459 (K)	East Hungu 1	East Hungu 1	5379	High	Low-Medium
Kdu_gl 462 (L)	East Hungu 2	East Hungu 2	5483	High	Low
Kdu_gl 464 (M)	Unnamed	North Chamlang	5205	High	Very High
Kdu_gl 466 (N)	West Chamlang	South Chamlang	4983	High	Low
Kdu_gl 533	Unnamed	West Hongu Glacier Lake	5400	High	Low

Review of Potentially Dangerous Glacial Lakes in the Hinku and Hongu Valleys

Dudh Kunda: Dudh Kunda (422) lies to the northeast of the village of Kothe at an altitude of 4,765 m, and is drained by the Sanu Khola. Some lodge owners in Kothe expressed concern over this lake, especially in terms of a possible outbreak flood and the danger that this posed to their lodges and other investments. Based upon topographical maps and satellite photos, the lack of adjacent and overhanging ice suggests that these potential triggering mechanisms pose little risk, but a full field-based geomorphological and on the ground survey is nevertheless recommended.

Tam Pokhari: The Tam Pokhari is erroneously shown as "Sabai Tsho" on the Schneider map (Nepal-Kartenwerk 1965, 1974) and contemporary trekking maps based on 1992 aerial photography (e.g., "Mera Peak Climbing Route" (Sherpa Maps 2004)). The photograph on the left below (2) was taken by Mr. Lhakpa Gylgen Sherpa, a lodge owner in Kothe, on the morning of 3 September, 1998. According to Mr. Sherpa, "The flood started at 5:00 a.m. and continued for 20 hours. People heard a loud noise and saw a huge white cloud from the ice avalanche." The outflow was gradual, "like tipping a glass of water over slowly," so that people in the Tagnag area could easily escape." The water flowed in surges, steady for a while and then followed by a swell that was high and forceful enough to take out bridges. There was a smell like gunpowder in the air, and two of the total seven houses in the settlement were destroyed. Two people were also killed downstream, one in Waku and one in Pawai. Bridges at Waku and Pawai were destroyed, and the Dudh Kosi was blocked for two years lower down, creating a long lake that eventually drained. Damage occurred south of Khare, still visible to this day on Google Earth.

The terminal moraine was dissected by the 1998 GLOF (3), through which a large amount of the lake water was discharged. 4 clearly shows the lowered lake level. The lower half of the lateral moraine has less vegetation cover, which had been under the water before the GLOF. Field measurements suggest that the water level lowered by about 60 m from the original lake level, although Dwivedi et al. (2000) provide an estimate of 50 m. The difference of 10 m reflects either measurement errors and/or a further lowering of the lake level since 1998 GLOF, and is in need of a more detailed assessment during the next field survey. A measurement taken by a micro total station shows that the relative height from Photopoint 1 on the moraine ridge (to the left of the photograph) to the lake level was 136.0 m.

2 (left): Tama Pokhari glacial lake outburst on 3 September, 1998 from Tagnag, shown here spilling over its south-facing terminal moraine (photo: L.G. Sherpa). 3 (right) shows the impact and riverbed scouring northeast of Tagnag on 17 October, 2009 (photo: A. Byers). Damage has been documented for 150 km downstream (Dwidevi et al., 2000).

4. Tama Pokhari from Photopoint 11 (see Table 2) (A. Byers, 17 October, 2009). Note the watermark showing the pre-outburst flood lake level. The relative height from the lake level to this photopoint is 136.4 m.

<u>Andra Pokhari</u>: Labeled "Tama Pokhari" on most maps, Andra Pokhari is in fact not a lake but a series of meltwater ponds within the Khare and Hinku Shar glacier valleys. The debris-free (“clean” or C-type) glacier of Peak 41 has receded from the valley to one-quarter of the way to the summit, while the debris-covered valley (D-type) glacier now contains numerous and small meltwater ponds. It is probable that the major melting of the glacier began in the 1950s, but that the overall steepness of the glacier delayed the melting rates of the C-type glacier on the flanks of Peak 41. The debris covering the valley glacier has also probably acted as something of a buffer to further melting, although considerable ablation can be observed.

5. The location of "Andra Pokhari" according to existing maps, which was found to be a series of meltwater ponds within the Khare and Hinku Shar glacier valleys. Peak 41 is located to the right (A. Byers, 19 October, 2009).

<u>Chamlang Pokhari</u>: Chamlang, listed as West Chamlang in Table 1 by Bajracharya et al. (2007), was considered by many to be a "dangerous" lake based on satellite image analysis. Interestingly, it is also considered to be dangerous by Rai shepherds as well (D. Rai 2009, pers. comm.). While it was observed that there is indeed considerable overhanging ice above the lake (6) that could be dislodged and cascade into the lake and in turn cause a surge, the length and surficial roughness of the region between the lake and the terminal moraine (i.e., the region below the meltwater ponds that can be seen to the left) suggests that any surge would most likely be buffered and repelled.

The team completed a bathymetric survey of the lake which is detailed in Sawagaki et al. (forthcoming). The bathymetric map shows that the current lake is about 550 m in width (north-south) and about 1,650 m in length (east-west). The lake was most probably very small in 1962 when a climbing expedition team from Hokkaido University scaled the summit of Mt. Chamlang. The lake area shown on the Schneider map (surveyed between 1955 and 1974) is roughly one-sixth of the current area. The bathymetric survey indicates that the maximum water depth is 87 m.

The terminal moraine of the Chamlang Glacier has five dissected channels, four of which are already abandoned. The largest channel located in the northwest of the terminal moraine has surface water (a small river), which is subsurface flow in the uppermost channel. The level of all others is located at much higher than the current lake level. These dissected channels suggest the former lake had overspilled when the lake level was much higher than today. The magnitude of the overspill was not large, based on the small size of the depositional landforms on the terminal moraine.

6. Chamlang Pokhari from Photopoint 25 (A. Byers, 26 October, 2009).

7. Chamlang Pokhari from Photopoint 23 (A. Byers, 25 October, 2009)

L442 (Mera or Hinku Teng Glacier): L442 appeared to be a "safe lake" because of its shallow depth (i.e., based on color and the fact that it was already beginning to freeze in October), distance from the receding Mera glacier (center of the photo), and lack of flood-triggering mechanisms such as overhanging ice. However, its rather small terminal moraine (far right), steepness of the Mera valley below, and lack of geomorphic buffers such as those found at Chamlang lake suggests that L442 could be of concern if it continues to grow, and is in need of regular monitoring. Presently, water is discharged from the lake beginning at a point about 30 m below the crest of the terminal moraine.

8. Lake L442 (A. Byers, 29 October, 2009)

L464: L464 is located to the northwest and immediately below Chamlang (7319 m). It was not specifically targeted as being "dangerous" by previous studies, possibly because much of the lake and adjacent geomorphic features are obscured by shadows in the satellite images used by analysts. 9 shows the lake from the south. 10 was taken from the west and provides a better overall view, including a range of geomorphic factors that may in fact be cause for concern. For example, an unnamed glacier at the lake's head debouches directly into the lake and could be a source of future cascading ice, based on its flat and vertical terminus. Four (4) overhanging ice packs were observed above on the north face of Chamlang, which could easily be dislodged by either future melting or an earth tremor. Like 442, the terminal moraine was observed to be small and easily broken in the event of a sudden surge. Unlike 442, however, the deep green-blue color of the lake, and delayed freezing mechanisms (based on comparative satellite image analyses) suggest that 464 is quite deep, which raises further concerns regarding potential glacial lake outburst floods. 464 is considered to be a priority study site for the future, and in need of bathymetric studies, downstream impact analyses, and mitigation method surveys.

9. Lake 464 from the south (A. Byers, 28 October, 2009).

10. Lake 464 from the west. Note the steepness of the feeder glacier, overhanging ice, and apparently great depth and volume of the lake. When combined with the small size of the terminal moraine dam (far right) and steepness of descent into the Hongu valley, 464 may be cause for concern and is in need of further field work and analyses (A. Byers, 28 October 2009).

L459-East Hongu Glacier Lake #1: L459 is located due north of a steep rock and ice feature that reaches an elevation of 5,762 m. However, there is no direct contact between the East Hongu glacier and the lake; there are no overhanging glaciers or ice packs from the rock massif above the lake; and the several kilometers of end moraine between the lake's end and descent into the Hongu valley would most likely buffer any sort of surge. 459 is therefore considered to be safe and of small concern regarding possible future glacial lake outburst floods.

A fresh-debris cone originated from the terminal moraine of the East Hongu Glacier dams the Seti Pokhari on the main valley (Hongu valley) bottom. The amount of the debris is so large that a possible past GLOF was speculated in the field. However, an IKONOS satellite image shows that sliding from the terminal moraine has produced many debris flows.

11. East Hongu #1. Baruntse is located to the far left of the photograph (A. Byers, 27 October, 2009).

East Hongu Glacier Lake #2: East Hongu Glacier Lake #2 is located to the northeast of East Hongu Glacier #1. It is a small and shallow lake that was already beginning to freeze when visited on 4 November, 2009. The terminal moraine damming the lake is large, high, and solid; there is no overhanging ice that could possibly trigger an outburst flood; and the East Hongu glacier terminus has receded approximately 25 m east of the lake's edge. The lake is most likely of little concern regarding possible outburst floods.

12. East Hongu Glacier Lake #2 (A. Byers, 4 November 2009)

West Hongu Pokhari: The West Hongu glacial lake is located about 1.5 hours' climb from the Hongu valley floor. Like the East Hongu Glacier Lake #2 discussed above, it is apparently quite shallow, the feeder glaciers have receded well beyond the lake's western-most edge, and there are no overhanging ice or other glacial lake flood triggers apparent. Finally, there is a wide expanse of debris-covered land between the lake's terminus and beginning of the descent into the Hongu valley, providing a level of surface roughness that would deter any possible flood or overflow.

13. West Hongu Pokhari. The region provides beautiful views of the south sides of Tamserku and Ama Dablam, and is the starting point for crossing the Mingbo La pass. Twenty years ago, Mingbo La was considered to be much easier than the Amphu Laptsa pass to the north and was more frequently attempted. However, glacial melting, rock and debris avalanches, and other surficial changes possibly related to climate change have now rendered the Mingbo La as much more difficult and dangerous than the Amphu Laptsa, with approximately 30 groups crossing the latter in 2009 (A. Byers, 2 November 2009)

449 (Hongu Glacier Lake): 449 is located below a D-type glacier that debouches into the lake immediately to the north (right side of the photo). The lake is fairly small, shallow, partially separated by

an old terminal moraine near its end, and has no overhang ice or other features that could potentially trigger a flood. As with several other lakes that appear to be largely benign, however, the small size and fragility of the lake's terminal moraine presents some concern in the event of unusual and rapid snowmelt and runoff. 449 therefore falls within the category of "not dangerous but in need of further study and monitoring."

14. Lake 449 (Hongu Glacier Lake). The lake is considered not to be dangerous but in need of monitoring (A. Byers, 3 November 2009).

Panch Pokhari #1: Panch Pokhari #1 is the third largest lake within the Hongu and Imja valleys surveyed, but is shallow in depth and lacks flood-triggering mechanisms such as glacier termini, overhanging ice, or unstable rock structures. However, its small terminal moraine, and rapid drop-off into the Hongu valley illustrated by 15, raise some concern of flooding in the event of high rainfall or runoff from snowmelt. The lake is therefore not considered to be of particular danger at present but in need of close monitoring and further field study.

15. From left to right, Panch Pokhari #1 and Panch Pokhari #2. Several other smaller lakes and meltwater ponds adjacent to Panch Pokhari #2 are obscured in the photo, but of little concern in terms of possible flooding (A. Byers, 3 November 2009).

Panch Pokhari # 2: Panch Pokhari #2 lies to the northeast of #1, a small but apparently deep lake beneath the Amphu Laptsa ridge and glaciers. The lake is relatively isolated within the Panch Pokhari au, there is no overhanging ice or other flood triggers apparent, and the terminal moraine dam is high. However, the lake's location immediately below the Amphu glaciers would suggest that it might be of greater concern than, for example, Panch Pokhari #1.

Glacial Lake Evolution 1964-2010

All nine of the major glacial lakes within the upper Hongu valley have grown significantly since the 1960s. For example, comparisons of Chamlang lake between Erwin Schneider's 1962 "Khumbu Himal" and "Shirong/Hinku 1:50,000" map (Nepal-Kartenwerk 1965, 1974) with the more recent Government of Nepal

Survey Department maps (1996) offer vivid, "slice in time" first approximations of these changes (see: Racoviteanu et al. 2008). Sawagaki et al. (forthcoming) utilized repeat satellite imagery to trace the lake's development since 1964 (Figure 2). The growth pattern shown in Figure 2 generally reflects that experienced by Imja, Tsho Rolpa, Dig Tsho, and other glacial lakes since the 1960s (see: Bajracharya et al. 2007; Ives et al. 2010; ICIMOD 2011).

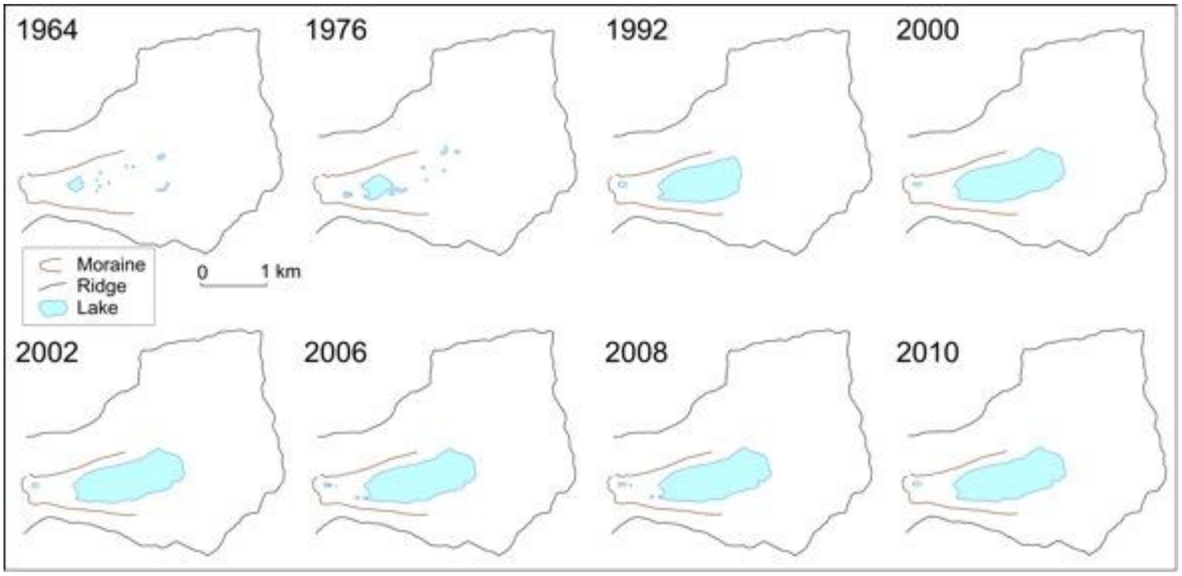

Figure 2. Growth of Chamlang South glacial lake since 1964 (Sawagaki et al. (forthcoming)

Table 2 Utilized remote sensing data and the lake area obtained by LPS

Date	Source/Sensor	Largest lake area (km2)	Total lake area (km2)
26 November 1964	Corona KH-4	0.034	0.045
03 January 1976	Corona KH-9, Hexagon	0.119	0.136
22 September 1992	Landsat TM5	0.639	0.639
30 October 2000	Landsat TM5	0.864	0.864
23 December 2002	Landsat TM5	0.868	0.868
04 December 2006	ALOS PRISM	0.865	0.865
24 October 2008	ALOS ANVIR-2	0.866	0.866
26 October 2010	Landsat ETM7	0.867	0.867

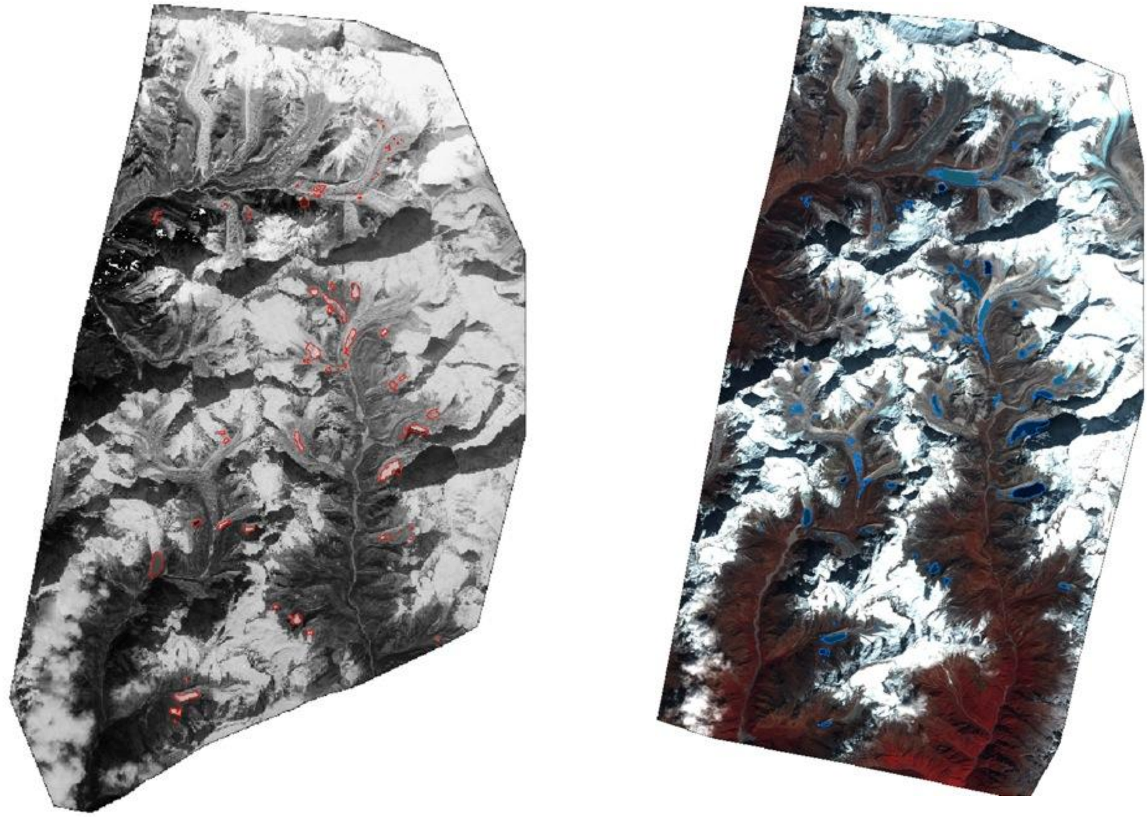

Figure 3. Hinku (left side of each image) and Hongu (right side of each image) valleys in 1962 (left image) and 1999 (right image).

As discussed, the 2009 expedition focused primarily on Chamlang South because it was identified by both scientists and local people as being one of the most dangerous lakes in the valley. Results are discussed in Sawagaki et al. (forthcoming), including the team's conclusion that the lake was not particularly dangerous because of various geomorphic controls as discussed previously. Rather, results of the investigation pointed to 464 (Chamlang North) as being by far the most dangerous lake in the valley because of an abundance of potential triggers, massive lake size, and unstable terminal moraine, to name several variables. Interestingly, the lake had not been listed within the "potentially dangerous" group, possibly related to the presence of shadows as mentioned previously. Because of the apparent threat imposed by the lake, and in the absence of on-site field measurements, a hydraulic model was developed to assist in the prediction of downstream impacts in the event of a glacial lake outburst flood.

464 Modeling: In order to reproduce the behavior of a potential GLOF at Lake 464 (N. Chamlang Lake) a one-dimensional simulation of a GLOF was performed using U.S. Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS) (USACE, 2010) for the hydraulic calculations and HEC-GeoRAS (USACE, 2009) for visualization. The GLOF is considered to be composed of pure water in this simulation, due to the difficulty of the problem and the complications of debris flow modeling.

A 30m x 30m resolution Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) digital elevation model (DEM) was used (Tachikawa, 2011) to represent the topography of the basin and provide a basis for delineating the basin (Figure 4). The streamline of the Hongu River was delineated using the DEM and Google Earth. The modeled portion of the river has a reach length of 130 km from the moraine dam of Lake 464 to the confluence of the Dudh Kosi and Sun Kosi rivers. The flow paths, banks, and Lake 464 moraine were digitized using Google Earth, and 689 cross-sections were extracted from the DEM using HEC-GeoRAS.

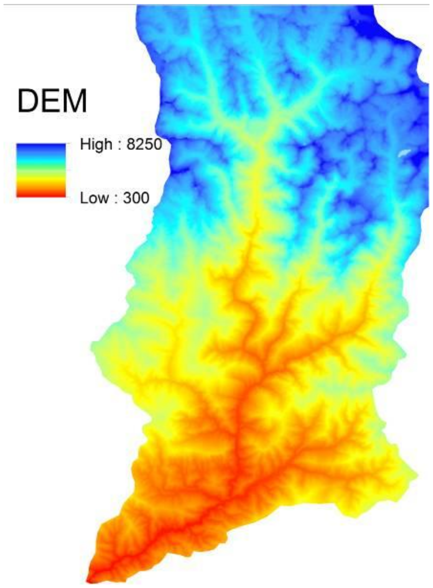

Figure 4. Digital elevation map of the Hongu River Basin at 30-m resolution

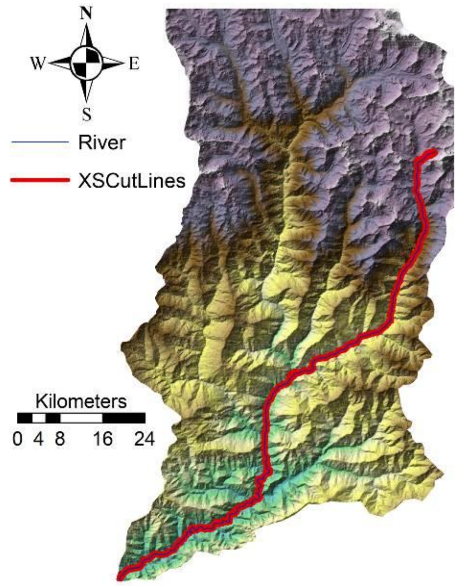

Figure 5. Output from HEC Geo-RAS for a potential Lake 464 GLOF in the Hongu River Basin.

HEC-RAS was used to perform the hydraulic calculations of a potential Lake 464 GLOF. Due to the unstable nature of the dam breach process the model parameters were calibrated to achieve greater stability rather than accuracy in the solution, since the terrain data are of coarse resolution, 30m; no more than 10m DEM resolution is recommended for flood calculations (USACE, 2010). The stability of the model is a function of the distance between the cross-sections and the time step used in the simulation. The minimum time step allowed in HEC-RAS is one second, which was used here. In addition, interpolation was used to derive cross-section with 2 m spacing in locations where greater solution stability is needed.

In order to calibrate the outflow hydrograph from the dam breach an empirical equation is used for the peak GLOF outflow from the moraine dam

$$Q_{max} = 0.0048V^{0.896} \qquad (1)$$

where Q_{max} (m^3/sec) is the peak discharge from the breach and V (m^3) is the volume of the lake (Popov, 1991 as cited in Huggel et al., 2002). A precise estimate of the lake volume was not available; so it was estimated using a second empirical equation.

$$V = 0.104A^{1.42} \qquad (2)$$

where A (m^2) is the surface area of the lake (Huggel et al., 2002). The area was calculated from an ALOS image taken on October 24, 2008 (personal communication, T. Watanabe, 15 October 2011) using ArcGis. The estimated surface area of the lake is 1 km^2. The estimated volume (Eq. 2) is 35 million m^3. The resulting peak discharge from the moraine breach is estimated (Eq. 1) to be 27,800 m^3/sec. Then the dam breach parameters were adjusted in order to obtain a similar peak outflow value in the HEC-RAS model. The breach is produced by overtopping since this is the most probable case. The full formation of the simulated breach takes 18 minutes. The depth of the breach is 31 m high, and the bottom width is 62 m. The river was considered to have an initial flow of 100 m^3/sec at the beginning of the simulation. Manning roughness coefficient (*n*) was considered homogeneous for the entire river with a value of 0.05 (Chow 1959).

The outflow peak occurs 16 minutes after the start of breaching. The peak flow rate in the HEC-RAS model is 27,261 m^3/sec, which is very close to the peak calculated using Eq. 1. Figures 6 and 7 show the water elevation and flow rate at cross-sections located at: (1) the moraine dam (River Section (RS) 127.625 km); and (2) at the confluence of the Hongu and Dudh Kosi Rivers (RS 68.451 km). The lag time between the peak flow at the dam (RS 127.625) and the peak flow at RS 68.451 km (Hongu-Dudh Kosi confluence) is 76 minutes. Hence, in this reach the GLOF traveled at 59.2 km/hr. Then the lag time between the peak flow at RS 68.451 km and the peak flow at RS 0.080 km (Dudh Kosi-Sun Kosi confluence) is 10.96 hours. Hence, in this reach the GLOF traveled at (6.24 km.hr). Almost all of GLOF water passed through the downstream cross-section, and there were no significant losses due to accumulation along the river. Nevertheless, the GLOF wave became more diffuse downstream because of the decreasing river slope. Table 3 shows model results at selected cross-sections in the Basin, indicating for example that the peak takes four hours to reach Rabuwa Bazar where it has a flow of 3024 m^3/s and a height of 2 m above the assumed normal water level. Further inundation mapping and analysis could not be completed due to the lack of appropriately high resolution topographic data.

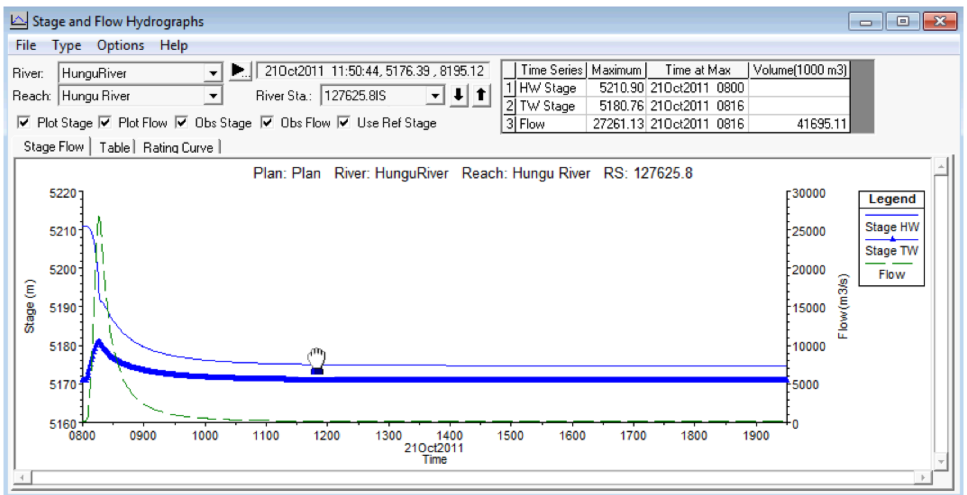

Figure 6. Dam breach hydrograph. HW: headwater, TW: tailwater (River Section 127.625 km)

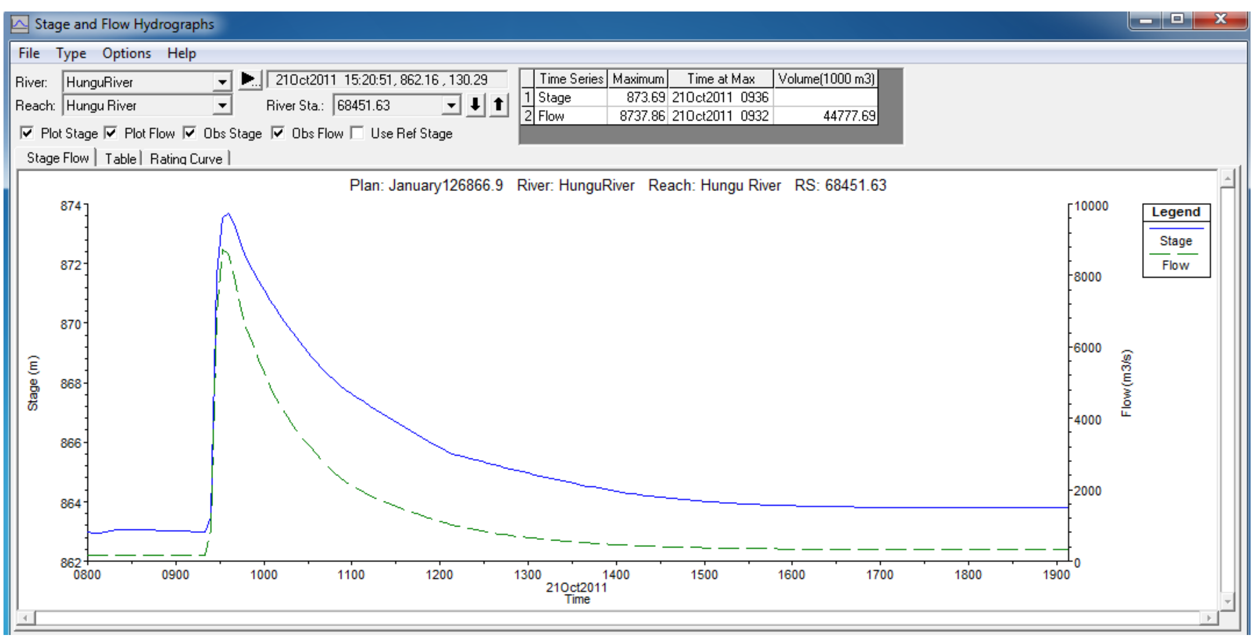

Figure 7. Hydrographs of the Hungu River at the confluence with Dudh Kosi River. (River Section 68.451 km) (wsel=water surface elevation)

Table 3 GLOF Model Results at Selected Cross-Sections in the Hongu River Basin.

Station	Distance from last x-section (m)	Peak Stage (m.a.s.l.)	Relative Peak Height (m)	Peak Velocity (m/s)	Peak Time (min)	Peak Flow (m3/s)
Point 1: Moraine	127510	5180	10	17.9	16	27264
Point 2	124877	4783	14.4	1.9	20	22588
Point 3	121469	4601	17	4.3	24	21510
Point 4	109769	3331	15	5.7	28	22009
Point 5	97169	1991	10	23	40	17043
Point 6: Bung	84898	1385	9	18.8	60	13036
Point 7:	68575	872	10	5	96	8839
Point 8	61971	730	6	1.8	112	7347
Point 9: Monjo	49500	516	7	2.8	156	5040
Point 10: Rabuwa Bazar	36600	452	2	6	240	3024
Point 11: Susp. bridge	25761	410	4	4.3	316	2599
Point 12	14040	392	4	5.8	456	1433
Point 13	8400	383	3.1	2.8	520	1386
Point 14	2400	383	3.2	0.1	620	1118

Conclusion: 464 (Chamlang South) is clearly one of the most dangerous lakes within the Hongu valley, if not in Nepal as a whole. Hydraulic modeling suggests that in the event of an outburst, triggered either by cascading ice or an earth tremor, a flood would result that would inflict massive damage throughout the length of the Hongu valley and beyond to the Ddudh Kosi-Sun Kosi confluence. Considerable loss of life, infrastructure, and agricultural land could be anticipated in the event of such a flood, particularly given that the vast majority of downstream residents are not even aware that the lake exists given its extreme remoteness and location in a wilderness area.

In Nepal and many other high mountain glacial regions, access, hardship, and lack of remote area experience are the main reasons for the current lack of reliable information and progress in dealing with the risks imposed by glacial lakes, as well as opportunities they may provide in terms of long-term water storage and other benefits. For example, the glacial lakes documented in this paper require an eight-day trek over two high mountain passes, one exceeding 5,400 m, simply to reach the uninhabited work site. Although of spectacular beauty, the Hongu Khola is extremely remote, challenging to work in, and terra incognita to the scientists responsible for the climate change, glacial recession, and glacial lake outburst literature and media attention currently growing in Nepal and elsewhere. Additionally, much uncertainty exists regarding appropriate methods for lowering the levels and decreasing the volumes of dangerous lakes to non-dangerous levels. This is perhaps related to the mixed results and tremendous expense of Nepal's only effort to manage a glacial lake, Tsho Rolpa lake in the Rowaling valley in the late 1990s (Bell et al. 2000; Bajracharya et al. 2007). As a result, many continue to argue that mechanical methods, such as controlled breaching or siphons, are too expensive for the Nepal Himalaya, and that early warning systems are the only practical solution (Bajracharya et al. 2007; Maskey, P. pers. comm. 2011). However, local people living below these new lakes are increasingly voicing their concerns and fears for their lives and safety, having experienced glacial lake outbursts as recently as 1998 that caused severe property and infrastructural damage as well as the tragic loss of life (Sherpa, S.I. 2008, pers. comm.; Ives 1986; Vuichard and Zimmerman 1986).

We argue, however, that methods of controlling, managing, and/or adapting to new glacial lakes in the Hindu Kush-Himalaya are not as insurmountable as some would propose. In addition to the superb remote sensing and modeling resources available, the evidence increasingly suggests that concurrent and on-the-ground field studies are also needed in order to arrive at the best understanding of any climate change-related problem and its prospective solutions (Byers 2007; Kargel et al. 2011). Scientists, practitioners, and policy makers alike need to search for ways to provide opportunities to young men and women to learn the best of the field and laboratory skills, in essence resurrecting the "climber-scientists" of previous years equally at home on the end of a rope as they are in front of a computer screen. Local people, long neglected by researchers, need to be involved at all stages of field research and pilot project design because of their knowledge of local landscapes and processes, need to understand the science behind climate change phenomena, and ultimate decision making position once risk reduction alternatives are known. South-south collaboration and exchange, particularly in learning from the Peruvian's 50 years of experience in controlling and managing dangerous glacial lakes, would also help to close the glacial lake information gap currently plaguing countries in Central Asia, Hindu Kush-Himalaya, and other glaciated mountain regions.

References

Armstrong, R.L. 2010. The Glaciers of the Hindu Kush-Himalayan Region. Technical Paper. Kathmandu: ICIMOD.

Bajracharya, B., Shrestha, A. B., & Rajbhandari, L. (2007). Glacial Lake Outburst Floods in the Sagarmatha Hazard assessment using GIS and Hydrodynamic Modeling. *Mountain Research and Development* , 27, 336–344.

Bell, W.W., Donich, T., Groves, K.L., Sytsma, D. 2000. Tsho Rolpa GLOF Warning System Project. In: Proceedings 28th IAHR Congress, Graz.

Bolch, T., Buchroithner, MF., Peters, J., Baessler M. and Bajracharya, S. 2008. Identification of glacier motion and potentially dangerous glacial lakes in the Mt. Everest region/ Nepal using spaceborne imagery. *Natur. Hazards Earth Syst. Sci. (NHESS)*, 8(6), 1329–1340.

Byers, A.C. 2007. An assessment of contemporary glacier fluctuations in Nepal's Khumbu Himal using repeat photography. *Himalayan Journal of Sciences* Vol. 4, No. 6: 21-26.

Carey, M., 2005. Living and dying with glaciers: people's historical vulnerability to avalanches and outburst floods in Peru. *Global & Planetary Change* 47, 122-134.

Carey, M. 2010. In the Shadow of Melting Glaciers: Climate Change and Andean Society, Oxford Univ. Press, New York.

Chow, V. T. (1959). Open Channel Hydraulics. Caldwell, New Jersey, USA: The Blackburn Press.

Cox, J. H. 1999. An assessment of habitats and human interaction in the Hinkhu, Hongu, Kasuwa and Barun Kholas of Makalu-Barun National Park and Conservation Area. Kathmandu: Makalu Barun Conservation Project, The Mountain Institute.

Dunsmore, J.R. 1988. Mountain environmental management in the Arun river basin of Nepal. Occasional Paper No. 9. Kathmandu: International Centre for Integrated Mountain Development.

Government of Nepal 1996. Sagarmatha. Sheet No. 278604. Survey Department.

Hambrey, M., and Alean, J., 2004, Glaciers, 2nd ed.: New York, Cambridge University Press, 376 p.

Huggel, C., Kääb, A., Haeberli, W., Teysseire, P., & Paul, F. (2002). Remote sensing based assessment of hazards from glacier lake outbursts: a case study in the Swiss Alps. *Canadian Geotechnical Journal* , 39, 316-330.

ICIMOD 2011. Glacial Lakes and Glacial Lake Outburst Floods in Nepal. Kathmandu: ICIMOD.

Ives, J., 1986. Jokulhlaup disasters in the Himalaya and their identification. ICIMOD Occasional Paper. Kathmandu: International Centre for Integrated Mountain Development (ICIMOD).

Ives, J., Shrestha, R.B., and Mool, P.K. 2010. Formation of Glacial Lakes in the Hindu Kush-Himalayas and GLOF Risk Assessment. Kathmandu: ICIMOD.

Kargel, J.S., Cogley, J.G., Leonarda, G.L., Haritashyac, U., and Byers, A.C. 2011. Himalayan glaciers: The big picture is a montage. Proc Natl Acad Sci USA, 10.1073/pnas. 1111663108.

Maskey, P. 2011. Hydrologist. Department of Hydrology, Kathmandu, Nepal. Personal communication, 10 September 2011, Khumbu, Nepal.

Mool et al. 2001. Inventory of Glaciers, Glacial Lakes, and Glacial Lake Outburst Flood Monitoring and Early Warning Systems in the Hindu-Kush Himalayan Region-Bhutan. Kathmandu: International Centre for Integrated Mountain Development (ICIMOD).

Moore, R. D., S. W. Fleming, B. Menounos, R. Wheate, A. Fountain, K. Stahl, K. Holm, M. Jakob, Glacier change in western North America: influences on hydrology, geomorphic hazards and water quality, *Hydrol. Process.* 23, 42–61 (2009)

Osti R., and Egashira, S. 2009. Hydrodynamic characteristics of the Tam Pokhari glacial lake outburst flood in the Mt. Everest region, Nepal, *Hydrological Processes*, Volume 23 Issue 20, Pages 2943 – 2955.

Racoviteanu, A.E., Williams, Barry, M. 2008. Optical remote sensing of glacial characteristics: a review with focus on the Himalayas. *SENSORS* 8:3355-3383.

Racoviteanu, A.E., Paul, F., Raup, B., Khalsa, S., and Armstrong, R. 2009. Challenges and recommendations in glacier mapping from space: results of the 2008 GLIMS Workshop, Boulder, Colorado, USA. Annals of Glaciology 50(53):53-69.

Sawagaki, T., Lamsal, D., Byers, A.C., and Watanabe, T. (forthcoming). Changes in Surface Morphology and Glacial Lake Development of Chamlang South Glacier, eastern Nepal Himalaya, since 1964. Tokyo: *Global Environmental Research*.

Shrestha, T.B.S. 1989. Development Ecology of the Arun River Basin. Kathmandu: International Centre for Integrated Mountain Development (ICIMOD).

Stainton, J.D.A. 1972. Forests of Nepal. London: John Murray and Company.

Taylor-Ide, D.; Byers, A.; and Campbell, J.G. 1992. Mountains, nations, parks and conservation: a case study of the Mt. Everest area. *GeoJournal* 27(1): 105-112.

Tachikawa, T., Hato, M., Kaku, M., and Iwasaki, A. 2011. The characteristics of ASTER GDEM version 2, IGARSS, July 2011.

US Army Corps of Engineers Hydrological Engineering Center. (2009). *HEC-GeoRAS (version 4.2) GIS tools for Support of HEC-RAS using ArcGIS® User's Manual* . Davis, Ca, USA.

US Army Corps of Engineers Hydrological Engineering Center. (2010). *HEC-RAS River Analysis System Hydraulic Reference Manual (Version 4.1).* Davis, CA, USA.

US Army Corps of Engineers Hydrological Engineering Center. (2010). *HEC-RAS River Analysis System User's Manual (Version 4.1)*. Davis, CA, USA.

Vuichard, D. and Zimmerman, M. 1986. The Langmoche flash-flood, Khumbu Himal, Nepal. *Mountain Research and Development* 6(1): 90-94.

Watanabe, T., Lamsal, D. and Ives, D.J. 2009. Evaluating the growth characteristics of a glacial lake and its degree of danger of outburst flooding: Imja Glacier, Khumbu Himal, Nepal. *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography*, 63, 255–267.

Xu, J., A. Shrestha, R. Vaidya, M. Eriksson, K. Hewitt. 2007. The Melting Himalayas: Regional Challenges and Local Impacts of Climate Change on Mountain Ecosystems and Livelihoods. Technical Paper. Kathmandu: International Centre for Integrated Mountain Development (ICIMOD). 15 pp.

Anticipating: Climate Change and the Construction of Scenarios in the Peruvian Andes

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Introduction: on the coming of the flood

Scene 1. I am sitting together with a small group of highland peasants on the rocks encircling a wheat-field in Poccrac, a small peasant community of the Andean province Recuay in Peru's Cordillera Blanca. From the field we have a spectacular view; the peaks of Tunsho and Huantsán are nearby, but the view also stretches down the valley where the imposing Huascarán and the neighboring triple peaks of Huandoy thrones the cordillera some 60 kilometres away. On my initiative, we start talking about the earthquake of 1970 that devastated large parts of the Callejón de Huaylas, and has been described as the worst incident of glacial floods worldwide. Poccrac also had its share of disaster, although on a smaller scale. Back then, the village was situated on the banks of the small stream known as Río Poccrac at the bottom of a ravine. The earthquake tore down most of the houses, including the school, and provoked massive mudslides that entered the village. Although nobody in Poccrac was killed, the event left its mark. Getting the news from other parts of the valley, the people of Poccrac realized that their community was located in a dangerous position. And so, the entire village was translocated to higher ground on the aus above the ravine. Knowing well that Poccrac got out of the earthquake quite safely, people started discussing the flooding of Yungay, which killed approximately 15,000 people. The question that emerged was whether that could happen again now that the glaciers continue to melt and feed the hungry lakes below. And more specifically, if Lake Querococha were to burst, would Poccrac then be safe?

The earthquake struck hard in most of the Callejón de Huaylas. In the Recuay area, the seismic waves also had an enormous impact, but it was unequally distributed. Recuay in itself was relatively unharmed, and the center of the town is virtually the same as before the earthquake. Huancapampa – just across the river – was hit way harder, and there are only a few remaining houses from before. One of them is Amador and Pascuala's house. Their house, with its 80 cm thick adobe walls, withstood the shaking ground. But many houses fell to the ground. Vast areas of the slopes leading to Shecllapata fell, resulting in a huge dislocation that can still be seen today. Catac, which is further south, was totally destroyed, and like Huaraz it is now consisting solely of recently build concrete houses.

The earthquake is a milestone in local history, and as I will argue, informs the way that people anticipate future events. In this paper I will scrutinize the construction of scenarios of climate change. I will briefly outline what climate change looks like from the perspective of the rural dwellers of Recuay, before entering the narratives of climate change. Finally, I will investigate the interconnections between the narratives of climate change and the construction of scenarios that form part of the process of anticipation. Before I go into that, I will discuss the core concepts of this paper, namely narrativity, scenarios, and anticipation. The questions I wish to investigate in the paper are firstly, how knowledge of climate change is generated, and secondly, how is this knowledge distributed and put into effect? When climate change is being discussed it is often done with reference to an idea of adaptation (cf. Adger 2009), frequently coupled with vulnerability (cf. Mark et al. 2010). While adaptation is valuable in many respects – which I will not go further in to at this point – from the perspective of the social sciences something might seem to be missing. And that is the relationship between the people and the environment that they live in, live by, and live with, because people do not only adapt to events that have already happened, but also towards future events. And the question that emerges is how to conceptualize the adaptation to events that have not yet occurred. In this paper I will suggest that we need to look into practices of anticipation, and how they come about. In other words, this is a paper on how expectations of the future are constructed upon experiences of the past.

Reconfiguring the world: on toads, rats and ants, rivers, rain and glaciers

That the world is constantly changing is no news, but the current climate change does seem to enforce a sense of vulnerability all over the globe. It can be hard to make a direct linkage between the perceived changes in the weather and the climate, as they work on different scales in both time and space. However, changes are being perceived, and the peaks of the Cordillera Blanca often serve as a reference point. In the mountains, there is visual evidence that things are not as they used to be. And the world is being reconfigured in many ways.

In a survey I conducted in the 97 households that constituted my core fieldwork area in the villages of Huancapampa, Ocopampa, Poccrac, and Cantu, I asked the respondents to estimate the changes in different types of weather phenomena. I asked them to compare them with the weather 20 years ago, and to state whether that particular element of the local climate had increased, decreased or remained stable. The results can be appreciated in Table 1.

Table 1. Temporality and Climate Change

Perceptions of climate variability – 20 years back and now

	Augment	Stable	Decrease
Rain during the season	40%	15%	45%
Duration of the wet season	28%	17%	56%
Duration of the dry season	58%	17%	25%
Intensity of the rain	66%	10%	24%
Flooding of houses	50%	37%	11%
Landslides	62%	29%	8%
Hail	86%	9%	5%
Intensity of the temperature in dry season	92%	6%	2%
Intensity of the temperature in the wet season	64%	22%	14%
Duration of frosts	92%	8%	0%
Duration of the cold season	70%	22%	4%
Duration of the hot season	49%	24%	4%
Frequency and duration of strong winds in the dry season	66%	23%	11%
Frequency and duration of strong winds in the wet season	53%	31%	16%
Melting of the glaciers in the wet season	79%	7%	14%
Melting of the glaciers in the dry season	40%	23%	37%

What can be seen from Table 1 is that many of the ordinary weather phenomena is actually quite hard to access whether they have changed or not. This is due to natural climate variability, the fact that the weather has always changed. Some years are El Niño years, others enjoy a visit from La Niña; sometimes it just simply does not rain when it was supposed to. They recall that their grandparents have told them about droughts in the past, that is, before climate change was an issue. Weather is always sort of random. But there are some phenomena which are out of the ordinary. Hail and frosts seem to have been increasing over the last decade, as has the temperatures – especially in the dry season. They told me that the nights have become cooler, whereas the days are much hotter now than they used to be. Hotter, and with a more burning sun that irritates both skin and eyes, scorching the soils of their fields. Finally, they report of slightly changing wind patterns.

Thus, there seems to be an increase of certain phenomena: hail, frosts and temperature, and to some extent, the winds. This is all bad news for the peasant communities. Furthermore, the numbers indicate another trend, although not unequivocally. I am accentuating this because it corresponds with the oral accounts of many of my informants – that is, that the rainy season is shorter now, but with increased intensity of precipitation.[1] This means that the same amount of water drops from the skies within a shorter time span. Also, reading the environment in other ways indicate that the hydrological regime has been changing. In Huancapampa they often complain that Atoq Huacanca has changed its nature. Doña Donata who lives right by the river bank has been forced to move to her other house because of fear of being washed away as happened some 20 years ago with the former church. Back then it was not associated with climate change *per se*, but rather with living under shifting weather conditions. But now, the former mayor Rubén Gomez explained to me the very first time I met him, Atoq Huacanca has changed its character. It resembles a "dry river," a *río seco*. By that he meant that the river has changed from that of a constant flow but with higher or lower levels of water, to becoming one that usually has hardly any water in it, but in times of heavy rainfall, the current turns violent. In other words, the river where the fox once cried[2] has become unpredictable. A similar story is being told of the major river that runs through the Callejón de Huaylas, Río Santa. As the saying goes, that river is no saint anymore.

The final enquiries of the table are regarding glaciers. The numbers are very ambiguous, and at first sight might seem futile to consider. But they actually do convey some interesting information regarding the point-of-view of the observers of climate change. To answer that question one has to have certain indicators. Whereas the other questions where experiential, the questions of glacial retreat are to a large extent indexical. To clarify, Peirce tells us about the index that it is like the weathercock – that is, we cannot see the wind, but from the movement of the weathercock we can deduce that it is windy. The weathercock is an index of the wind. In very much the same way, annual glacial retreat must be indexical, whereas long term glacial retreat is experimental, i.e. can be observed by the darkened peak of Tunsho, for example. Thus, in order to speak up about glacial melt, one cannot necessarily look with accuracy on the glaciers, but must rely on indexes of the environment such as the amount of water in the rivers and lakes.

The Andean peasants rely on reading the environment in order to plan their working cycles in their fields. This sort of vernacular anticipation is based on knowledge of observation of particularly small animals and clouds. But some have gone missing. The toads that used to announce the coming and going of the rain are virtually extinct, as are a special type of ant that used to climb the wall and tree trunks whenever rain was approaching. Other animals have arrived. The most notorious and unwanted is the rat. Some have a different story, though. A few years back, Recuay renovated its entire sewage system and installed new tubes. These had come from Chimbote on the coast, and according to some, the arrival of the rats coincided with the arrival of the coastal tubes. While this may be plausible, it also tells a story of the perception of the coastal areas as polluted and immoral – a story that I will come back to later.

What should be drawn from this is that climate change introduces and enhances a sense of uncertainty. The weather and the environment change their configuration, and that calls for interpretation and anticipation. After a brief introduction to the idea of anticipation and its connections to narrativity, I will move further into three different narratives of climate change and the basis for anticipation that they constitute.

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[1] This is consistent with observations from other parts of the Andes and beyond, i.e. Postigo in Quelcaya, Pærregaard in Cañon del Colca, Chodhury in Nepal Himalaya among others.

[2] This I have explained elsewhere; the story goes that a fox (atoq in Quchua) once got caught on one side of the river, and could not pass it because of the strong current. Atoq Huacanca literally means "the place where the fox cried."

Past and Present: Narrativity and the Construction of Scenarios

According to the dictionaries, to anticipate means to foresee and act upon a future event. This act of forecasting requires the capacity to imagine what the future might look like, and the central question is therefore how the anticipation is put into play. Through the word itself – either in its form as a verb or as a noun – it is not possible to know whether anticipation is about the coming of bad or good. The anticipation that I shall discuss in this paper is about the perceived dangers that the environment presents. However, as I have treated elsewhere (chapter 7 of my thesis), anticipation is also about more earthly practices such as fumigating at the right time in between rain-showers. As Anthropologist Kirsten Hastrup rightly underscores, anticipation is an integral part of human agency. In every action that we undertake, we have some sense of a future to come, either immediate or distant, and we engage in predictions, projections and forecastings (Hastrup 2011: 25). Thus, anticipation is embedded in everyday life. However, my primary concern is limited to the narratives of climate change – the Big Story (Hastrup 2011: 26) – but in the final part of the paper I will return to the issue of implications upon everyday life. Beck writes in his seminal 1992 work that *risk* is about the *anticipation of danger*. Though I do not believe that his notion of the risk society is necessarily applicable to Andean society, this basic conceptualization is helpful for the understanding of anticipation and the current context of climate change in which it works.

If anticipation is such a common and even mundane practice, why is it so important to consider? Hastrup argues that climate change confronts people with uncertainties of an unprecedented magnitude. The central quality of climate change is that it is at once a very local and extremely global phenomenon. The local and the global conflate in a way, and it is not possible to distinguish between parts and the whole – for where does weather end and climate begin? Altering the environment – and, as collateral, the usual patterns of prediction – climate change presents a challenge to human engagement with the environment. The human capacity for anticipating is shaped and stretched within knowledge practices dependent on various degrees of records, experiences, and observations (Hastrup 2011: 2). This means that anticipation is always based upon different ways of knowing about the world. What we can see through the narratives of climate change is that it is not only about risk – that is, the *anticipation of danger* (cf. Beck 1992), but also that climate change produces both ontological and epistemological uncertainty. Hastrup writes that "the distinction between known or at least identifiable *risk* and unknown and maybe even unknowable sources of uncertainty and *fear* (partly owed to Bauman 2006: 100) is important for our concern with anticipation" (Hastrup 2011: 3). The question then, is not only what will happen, but more fundamentally why, how, and to what effect.

Anticipation is a space of pro-action that is created by a certain imaginative future; the scenario is thus the foundation upon which the anticipation is constructed.

Hastrup further argues that "the liquidity of the climate scenarios is itself a social driver; it infiltrates the perception not only of the environment but also of social life and knowledge." Like Hastrup (2011), I am concerned with the process of how climate variability is incorporated and projected into a horizon for the future.

Anthropologist Vincent Crapanzano (2004) discusses the idea of imaginative horizons. An imaginative horizon is a projection of the *hinterland*[3]; that is a scenario that cannot be transgressed either in time or space but which informs the present in various ways. The hinterland is thus a product of the imagination, an imaginary 'that gives us an edge, at times wrenching and painful, at times relieving and pleasurable, on the here and now in all its viscous immediacy' (2004: 14). In the present paper, I am interested in the imaginative horizons in a very particular way; that is, the hinterlands of climate change.

Narration and narratives are ways of speaking about the future while talking about the present. Michael Jackson (2002) underscores that narratives are ways of interrelating. Drawing on Arendt he argues that storytelling is a strategy for transforming private into public meanings. Secondly, he sees storytelling as fundamentally existential, because it serves as a "vital human strategy for sustaining a sense of agency in the face of disempowering circumstances" (Jackson 2002: 15). The existential and phenomenological

[3] Crapanzano has taken the idea of the hinterland from the French poet Bonnefoy. The hinterland, or the arrière-pays, is a place "to which we never quite arrive, for it always slips away. They resonate our fears of a beyond – of the imaginative possibilities it holds – and the hope those possibilities inspire" (Crapanzano 2004: 38). For Crapanzano, the hinterland is in all kinds of cultural expressions. In this paper, I have limited Crapanzano's scope drastically.

scope of Jackson's work is somewhat distant from the aim of this paper. His stories are personal accounts from a context of violence in sub-Saharan Africa. Nonetheless, his point that stories are used to reorder and make sense of the way life unfolds itself without actually – or necessarily – enhancing the conceptual or cognitive understanding of the world is important. This means, that the narratives work "at a 'protolinguistic' level, changing our *experience* of events that have befallen us by symbolically restructuring them" (Jackson 2002: 16). Whereas the informants talk about these events directly, in the case of narratives of climate change the current events are addressed somewhat indirectly, in that the subject of the speech has not yet happened; the dramatic event has not yet occurred. Thus, while narratives for Jackson are intersubjective, highly personal, and therapeutic, in this case, they are public and draw upon different configurations of knowledge and experience. Anthropologist David Turnbull (2004) investigates how in Aboriginal Australia, knowledge is being configured in different ways through narrative practices. Scrutinizing the negotiations in court between Aboriginals and "white" Australians as encounters of knowledge, Turnbull highlights that narrativity is a means of creating order and sense of the world; people are storytellers (ibid.: 169). "To tell a story," Turnbull argues, "is to organize things in space and time and vice versa; to reference and factor events and people temporarily and spatially is to construct a narrative" (ibid.). By creating coherence in time and space, narratives are creating ontologies; this means that it is through ordering events in time and space that the world is ascribed meaning. The narratives are stories about the world, and peoples' place in the world, and it is therefore essential to understand this narrative process of world-ordering. Like Hastrup, I therefore wish to draw upon the French philosopher Ricoeur. Hastrup writes, "One of the characteristics of narration, so admirably analyzed by Paul Ricoeur, is its capacity to make a whole out of individual episodes through a particular employment (Ricoeur 1984). The succession of events is integrated and transformed into a configuration. Climate stories, too, depend on a particular plot for them to be convincing, meaning comprehensive and sufficient for people to take them at face value" (Hastrup 2011: 9). The question is which plots are being used to configure the narration; in what ways are the events connected.

In the following I have identified three lines of plot, or three narrative strings, if you will. The separation between them is not welded shut, but can be interchangeable as the story progresses. However, as I will argue, they are commentaries of different aspects of climate change and thus tell us something about the different strategies of anticipating that are being employed by the rural *recuainos*.

Conscience and Contamination: contributions to global warming

Scene 2. At the meeting in Los Andes de Recuay, people were in a heated discussion about the burning of pastures that had been going on for the last week. Since the ban imposed by the National Park and the Ministry of the Environment, burning pastures had been punishable by severe fees that nobody in the community had the money to pay. Burning pastures used to be a common practice in the area, because it removed the dry straws of the *ichu*, thus giving room to fresh buds in the otherwise extremely dry grass at this time of the year. Another reason was that the smoke from the burnings would turn into clouds that would then initiate the expected rain.

But recently, there had been burning in Shecllapata, Purhuay (Yanahuanca) and Chinchin (Shecllapata). I myself had noticed the burning some days prior to the meeting, when I met Esteban Mallqui, drunken and upset, in Huancapampa. He pointed at the hills going to Shecllapata, complaining that somebody had set his pastures on fire. But nobody seemed to know who had actually set fire to the pastures; or at least, nobody wanted to tell. According to the villagers there where three possible perpetrators. It could be locals who wanted to continue the practice that is said to be of benefit to the sheep. Another group under suspicion was bored youngsters from Recuay. Finally, some were blaming the political candidates from the elections, because they were giving away matches, thus facilitating the access to fire. It should be added that, according to people outside the peasant community, a fourth option would also be possible: that somebody from the inside had deliberately set the pastures on fire. People then started debating the ban, which has been imposed in order to avoid the pollution that these burnings cause in the area, and in order to maintain the fragile highland ecosystems. There was general agreement that it is important to avoid pollution because it leads to the continuing deterioration of the glaciers, but then Emilio intervened in the discussion by asking if the others remembered how much they used to burn before. And then he added: "Back then it didn't pollute at all." (*¿Te acuerdas como quemábamos antes? Y ahí no contaminaba nada.*) This of course raises the question of the nature of pollution, and when a scientific explanation of a phenomenon enters the cultural understanding. What we are witnessing here in this process is actually a change in paradigm, where the smoke goes from being a trickster of rain to becoming the destructor of glaciers.

Orlove et al. (2008) note that climate change often functions on a different scale than its consequences. But the example from Los Andes de Recuay may tell a slightly different story; here, climate change and its effects are working on a similar scale. Whether the burning of pastures, the everyday contamination of rivers with plastic bottles or the dark exhausts from the buses that transport them to Huaraz or Lima, these are everyday small-scale contributions to climate change. From radio, television, and the occasional *capacitaciones* in the villages, people are very aware that contamination leads to a heated climate. The foundation of the interpretation is scientific. They are using references to, for example, the deterioration of the ozone layer (which is a different issue, although it can also ultimately affect the climate) and the increasing burning sensation from the sun. But the focus is on the localized forms of contamination, and thus responsibility of the changing meteorological conditions is put upon the villagers themselves. This reflects the fact that contamination in itself is not an endemic concept, but one – to a large extent like the contamination itself – that has been brought upon Andean society. In this version of climate change it is a much localized concept, which is virtually void of political power, but loaded with symbolic power. It is a story about their own self-perceived ignorance. Climate change in that context is seen as the result of a poor educational level and the lack of "conscience" among the villagers. *Conciencia* is a local term often employed by the villagers themselves to describe a state of a lack of knowledge, and more importantly, a lack of capacity to act upon this knowledge. From this perspective, there are things that people ought to know, but due to their social marginality and self-perceived inferiority at the margins of society they do not possess this intellectual capacity. Knowledge, insights, and appropriate action is defined from the outside; the villagers themselves need to be *capacitados*; i.e. educated. The knowledge that they themselves possess – that is, knowledge about agricultural practices and livestock care – is now rendered obsolete within the national community. Thus, it is also a story about rapid social change, where old customs are being replaced by new forms of social behavior and economic activity. I will return to that shortly. First I shall touch upon the second narrative of climate change. Whereas the first was void of economic and political power, but filled with power-as-knowledge, the second narrative is loaded with societal inequalities.

The big conspiracy: global climate change seen from the margins of society

Scene 3. As I was walking down from Yanahuanca with Evaristo and Agapita, a brother and sister from Poccrac, we started talking about the changes in the weather. Ever since I first met Evaristo on the main square in Recuay he had been very keen on talking about climate change. Back then I had told him that my aim for being in the area was to study how they manage water. His face had illuminated when he explained to me that this was the right place to come; in his village, Poccrac, they were already lacking water, and people were sometimes fighting over this scarce resource. Therefore, I should definitely come and visit them! Seven months later we were returning from the meeting on the statute from the Querococha 3 Bases that I have treated in chapter 6 of my thesis. A look at the barren rocks of the Tunsho Peak that were once covered with white prompted him to talk about climate change. We had discussed the issue on numerous occasions, but this time another dimension was added to climate change: Back in Lima I had recurrently been both annoyed and intrigued by some old friends' continued talk on conspiracy theories that combine a few families (13) controlling the world, corporate economies, and the imminent end of the world in 2012. And now, on this mountain slope far away from metropolitan Lima, Evaristo started echoing their claims. It had started five or six years earlier, he said, when the planets of the solar system stood in a certain position, the alignment which will cause great destruction – of which the melting glaciers were an effect. A world-elite knows about this, and are planning to save themselves in huge spacecrafts that will leave Planet Earth while the poles shift place. The plot of Evaristo's version of climate change resembled that of the 2009 disaster blockbuster "2012."

Climate change in this narrative is a matter of global and national inequalities, the result of the big corporations, the mining companies, the industrial clouds that rise from the cities on the coast. In other words, it is the global neoliberal regime that thrives on the poverty of the rural Andean populations. These are perceived as relations of exploitation not unlike those of the pre-agrarian-reform era (see Mayer 2005). In this, the people of the Andean villages are once again put at the bottom of the national food chain, suffering the consequences of the chimneys of those in power. Evaristo's account is without doubt a perverted version of this narrative; with its focus on clandestine global elites it is a commentary on the ways the economic systems function from the perspective of the margins of society. Whether it is the 13 families that rule the world or the national political elites, the end result is the same. It is a story about a political and economic upper-class that is possessing knowledge and resources, but its members are unwilling to share with the public. Contamination in this narrative is a foreign force that is being imposed upon the disempowered. But it also contains the germs for social protest; the perpetrators are identified and climate change has an agent that can be blamed. Thus, this narrative contains food for arguments. It is, in a way, revolutionary knowledge. While the disaster of 1970 cannot be attributed directly to the current state of affairs, the authorities' handling of the situation can. Thus, as natural phenomena they may be of a different kind, but the earthquake and the melting glaciers are both entangled in webs of political and economic interest.

As all good conspiracy theories, this one is a mixture of experience, scientific fact, and a certain way of connecting the dots, creating the narrative plot. The great clouds that allegedly rise from the industries on the coast, covering the sky and causing the glaciers to melt, are thus also symbolic. It is those on the coast that are the principal perpetrators – the coast, which is often characterized as being a place of pollution, immorality, greed, delinquency, and constant movement. That is the cloud that rises to the Andes. The Andean communities have experienced a long history of population exodus, as people have migrated from the small peasant communities to the large economic centers on the coast, such as the capital city Lima, and, particularly for this area, Chimbote and Trujillo (cf. Pærregaard 1997). The relationship towards the urbanized coastal areas is ambivalent; it is both perceived as a place of economic, social, and cultural opportunities that cannot be found in the Andes, and as a place where the traditional values have been eroded. Thus, in the minds of the villagers from Poccrac and beyond, while there might be an economic superiority to the lives on the coast, morally it is inferior. The narrative of the economical elites contaminating the environment and eroding the livelihoods is a story of a country that is still permeated by social inequalities; and, the logic goes, when disaster comes, the selfish elites will most likely look after themselves as they always do.

Apocalypse now: biblical and other fantastic interpretations of the melting glaciers

Scene 4. Señora Romero and I were walking across Jircacancha in Cantu to see if we could find Mónica, one of her fellow "sisters" from the Pentecostal church. As we made our way through the *ichu*-grasses of the plain, she was prompted to talk about climate change when I pointed to Tunsho, which towered over the vast puna of Shecllapata. I knew her son Efraín pretty well, and he was the one who had introduced me to her, so I knew that she, like many in Cantu, was a devoted adherent to the Pentecostalist congregations in Recuay. She started explaining to me that the melting glaciers are mentioned in the Bible, and drew out a leather-bound pocket-version of the Holy Book. In an instant, she pointed to a paragraph in the Bible where the coming of the end of the world is described, and where she claimed the melting of the glaciers was mentioned.

All over the Global South, the Pentecostal churches are experiencing a growing number of followers (Robbins 2004). In the Recuay-area, the tendency is the same, although the Catholic Church still is by far the larger of the two. Cantu is known as a Pentecostal stronghold, but the church also finds it devotees in Poccrac. I had heard about the Bible mentioning the end of the world many times before that. The first time was when I was helping Roger, a young man from Ocopampa, and his aunt harvest wheat in Shecllapata. She used to live there, but one night shortly after her husband passed away and she was left alone, the house was robbed. She was at home, and the burglars tied her to a chair, poured kerosene over the house and set it all on fire. Fortunately, she managed to escape, and decided that it was too dangerous to live there on her own. She moved to Huaraz, but kept cultivating her fields. She became a strong believer in the Pentecostal message, and that day in the wheat-fields she started talking to me about the end of the world. In the Bible, she told me, it is mentioned that people will kill each other like dogs in the field. As it had almost happened to her back then, and as it continuously keeps happening when the *abigeos* are at work. This was shortly after the incidence at Cochapetí, where six men had disappeared pursuing a band of cattle-rustlers. Also, the big earthquake of 1970 was a sign, as was the melting glaciers. Thus, in her mind all these events are signs of an larger event soon to come.

In this narrative we can see events of a very different nature that are connected along a line of thought that presupposes God's wrath. Climate change in this narrative is connected to morality; both of self and others. While one's own morality is the security of a well-deserved afterlife, the morality of others is seen more as a sign of the Apocalypse soon to come. Contrary to the other narratives, there is a certainty connected to the Pentecostal explanations of climate change. Like Jesus himself, they believe that the end of the world is near. Being part of the true faith, they also believe that Judgment Day will be their salvation from their earthly suffering. So, although the melting glaciers mark the end of the world, it is also partly a joyous event.

The earthquake was an extremely violent event, and one that is being referred to again and again, and the effects of that day can still be detected today. Also, the earthquake stands as a milestone in time; there is a time before and after the earthquake. The tectonic movements initiated social movements, and according to the *Huancapampinos* sparked the exodus of a large number of people. The effects were also felt inside the community, as the earthquake seems to be the root of a process of social disintegration. I have been told many times how the old times of social coherence ended that day.

Ways of Knowing: Sources and flows of information

Anticipating is about knowing, and about practices of knowing. However, knowledge is not neutral as it has been argued by Foucault (1980) and his numerous successors, but embedded in larger power relations. In her study on the social dramas evolving around the marine park at Tanzania's Mafia Islands, anthropologist Christine Walley (2004) examines the workings of knowledge and power in the "bureaucracy as a site for social struggle." She argues that knowledge is within the national park, knowledge travelled along two different tracks. While the scientific and technical knowledge was circulated through bureaucratic channels at national and international offices, popular knowledge[4] was far more circumscribed. Through an analysis of the knowledge encounters, Walley shows how the hierarchy of knowledge is played out in negotiations; there are certain forms of knowledge that rank higher than others, meaning that the scientific knowledge often overrules popular insights into local affairs. Knowing, she continues, is thus a way to enact the unequal power of social relations, and is bound to issues of ethnicity and modernity. Possessing a certain kind of knowledge thus underscores a social position. Upon my arrival, and long into my fieldwork, it was assumed that I was an engineer, and I never actually managed to shed that idea completely; I was the engineer-anthropologist. But due to my skin-color, they assumed I *must* have been knowledgeable of such matters. In Walley's account, she argues that the institutional dynamics of bureaucratic practices have led to an exclusion of popular knowledge, thus enforcing the pre-existing social hierarchies. While Walley is concerned with the clash of forms of knowledge, and the uneven power relations that are at play in the bureaucratic setting on Mafia Islands, my interest lay in the meshwork of hierarchical forms of knowledge. One thing is the admirable identification and tracing of forms of knowledge that Walley performs, another thing is how these sometimes diverging forms of knowledge are being put together. Thus, I will argue, in the construction of scenarios, popular and scientific knowledge are being brought together in a coherent way through the plotting of the events. And, it should be noted that even the purest scientific and technocratic account is subject to employment.

People, especially of the middle-aged generation, in the area often lamented their lack of knowledge. The sense of cultural loss was often predominant, as was that of inadequacy. Evaristo had told me how his mother had foreseen the melting of Tunsho, and told him that once Tunsho was gone, the end of the world would be approaching rapidly. "Tunsho" in Quechua means "marrow," and among my informants in Recuay it was commonly believed that Tunsho was like the spinal cord of the Cordillera Blanca. That also implied that breaking Tunsho, i.e. making the glacier disappear, would mean fatally damaging the entire Cordillera Blanca. But this is a kind of knowledge that is generational, belonging now to the *abuelos*. On the other hand, the youngsters are attending school, and a growing number are being educated at the universities. They introduce new ideas, and new forms of knowledge into the communities. While a vast majority of the people of Poccrac have been residing for shorter or longer periods in the larger cities on the coast, it is their sons and daughters who are taking the steps of partaking in the coastal production of knowledge. Thus, while highly knowledgeable about local matters, I often heard the middle-aged people, such as Evaristo, complaining that they possess neither the ancient knowledge of their forefathers nor the western knowledge of the younger generation. The question that emerges in this context is which kinds of knowledge are being made accessible, and also to some extent understandable. It is therefore worthwhile, considering the sources of information.

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[4] That is her term.

In Ocopampa, the church was filled with migrants and residents who had come to attend the mass of Padre Paulino, who had come from Recuay. The *Ocopampinos* were celebrating Saint Bartolomé, whose idol had come to the village more than a hundred years ago. Padre Paulino started the mass, and was talking about the Apocalypse and the precarious lives of human being not only in Ocopampa, but also in Recuay, Ancash, Peru, and the entire Globe. He ended the ceremony after 45 minutes with a talk about climate change, and the threat it poses towards *Ocopampinos* – and humanity at large. Ideas of climate change obviously enter the rural communities in various and sometimes mysterious ways. The ceremony of the Catholic priest underscores that even though the Pentecostalists and other evangelists do have very dramatic interpretations of the melting glaciers, preoccupation about them is not theirs alone. Likewise, the visiting migrants are also carriers of information from the coast. Newspapers and television from the national broadcast companies often contain recent data and the occasional catastrophic scenarios. Local radio stations, which continue to be the most important source of information, also air stories of climate change from time to time. In other words, local experiences of climate change merge with the national narrative of climate change (whatever that is!).

The hierarchies of knowledge are evident in the narratives that I have treated here. Knowledge about climate change is often being delivered as *information*, i.e. the villagers are being taught about the state of affairs. This is the process that Strathern describes, in which information about something becomes knowledge for someone (2004: 467). Through the narratives, the (quasi-) scientific information is being transformed into knowledge; it is in the encounter between the information, lived lives, and experience that knowledge is being generated. It is upon this knowledge that ideas of the future come into being. That is the horizon; an imaginative possibility (Crapanzano 2004: 45), or a scenario that is being informed and constrained by different forms of knowledge and experience.

Anticipating the Unknown: Instantiations of the future in the present

Returning to the wheat-field in Poccrac once again, the people's preoccupation with Lake Querococha is probably beyond the actual consequences of an outburst of that particular lake. Poccrac should be safe. But the preoccupation with the future of Poccrac is nonetheless very real; it is, in many ways, a community under threat. A heavy exodus of people due to a multiplicity of entangled uncertainties – economic, social, and environmental – has decimated the population of Poccrac. Compared to the population of 20 years ago, about half the number of people now lives in the scattered houses on the au. The rest have either died or moved elsewhere. In this paper I have tried to connect their preoccupation with Lake Querococha to past and present events. There is a social messiness to the argument; faithful to their accounts, conceptual leaps have been made. There is no direct linkage between the events of 1970 (or 1941 for that matter) and the present day events; yet, conceptually they are being connected in various ways. In this paper I have discussed divergent forms of interpreting the current events that unfold. In different ways they relate to previous events that inform the ways that the future is looked upon. The elements that are connected only vary slightly, but the ways that the plot is being constructed along the narrative string are highly diverse. These narratives are not person-bound, although some are more prone to certain explanations than others.

The argument in itself is quite simple, and philosophically it can be said to go as way back as Kierkegaard who writes in "Oieblikket (1877) that *the moment* is constructed with reference to both the past and the present. Thus, there is a certain (western) linearity to the narrative structures that I have treated. Although there is only a deliberate, outspoken "world-ending" (cf. Crapanzano 2004, ch. 7), or eschatology, in the Biblical interpretations of the event, there is a general sense of a break-up of the natural order of things in the Andes in all the narratives. In other parts of the Andes, people might have been making references to Pachacútec; that is, a cosmological notion that refers to the reordering of time and space that initiates history anew (cf. Risør 2010: 236). In other words, a cyclical conception of time that is perhaps more widespread in the Southern Peruvian Andes and into Bolivia. The "imaginative horizons" that inform the different narratives – and vice versa, the narratives that inform the imaginative horizons – can be said to have been built upon a certain "social imaginary," (Taylor 2004) of which Pachacútec takes no part. Instead, the localized imaginative horizons of Poccrac are being informed by particular events, particularly the 1970 earthquake which, with all its devastating power, plays a crucial role in the collective history. As a milestone of recent history, the earthquake is thus a crucial reference point, even for those who did not live through the actual violent movements of the earth. But stories of houses collapsing, roads blocked, and governments failed continuously brings the past into the present, and not only serve as tales of a disaster that once was, but also comments on the present and anticipates the future. The narratives are thus different configurations of knowledge about climate change, where elements are foregrounded or backgrounded. The narratives clearly show that climate change, even though its effects may be drastic and devastating, never comes alone. Even though these ideas of climate change often involve scenarios of catastrophe, and even the Apocalypse, people continue to live with the present.

An important point to take from Hastrup in her considering of anticipation is that the concept challenges the common views of adaptation that are often found in policy documents, for example. (Hastrup 2011: 26). As the narratives come to show, people are not just responding to a changing environment but actively engaging with it. In this way, the issue of anticipation underscores the complexities of human-environmental relations. Because people do not just live *in* or *of* the environment; they live with it, dwelling as Ingold (2000) would have it. The events – past, present and future – contain meaning, that is being constructed through plotting; this means that the events are being connected with a certain story line that moves beyond the present into an imaginative horizon of the future. Through the particular practice of knowledge that is the narrative, the future is being instantiated in the present. In other words, I argue that narratives are not only devices for ordering past events, but that they also point to the future. The narratives that I have treated here work on different scales of time and space. The anticipation implies a theorizing of the world on a specific scale; change the scale and the anticipated outcome changes.

Climate change has a certain scale-changing quality to it; local events can have global causes, and global impacts. The glacial lake outburst that sparked the initial scene in this paper can be said to be both strictly Andean and part of a global phenomenon. As Mark Carey (2010) writes in his eloquent historical analysis on climate change and glacial lake outburst in the Callejón de Huaylas, it is extremely hard to differentiate between the natural climatological oscillations and the anthropogenic climate change and assess their role in the 20th century disasters. But what can be said is that the likelihood of future disasters is increasing as the glaciers continue to withdraw themselves, leaving behind them the weak moraine deposits. Thus, while Poccrac may be out of the danger zone, the people's preoccupation with lake-security in times of climate change is not far-fetched. And that is why, when they talk about the earthquake of 1970, they are also talking about the future. In this way, we see how Andean society is perforated by climate change, and becomes part of and partakes in the global imaginaries of climate change.

References

Beck, Ulrick (1992) Risk Society. Towards a New Modernity, London: Sage.

Carey, Mark (2010) In the shadow of melting glaciers. Climate Change and Andean Society. Oxford University Press

Crapanzano, Vincent (2004) Imaginative horizons: Univ. of Chicago Press.

Foucault, Michel (1980) Power/knowledge: Selected interviews and other writings, 1972-1977. Vintage

Hastrup, Kirsten (n.d.) Anticipating Nature: A Space of Productive Uncertainties, in Anticipating Nature (forthcoming)

Ingold, T. 2000. The Perception of the Environment. Essays in Livelihood, Dwelling and Skill. London: Routledge.

Jackson, Michael (2002) The politics of storytelling. Copenhagen: Museum Tusculanum Press

Kierkegaard, S. (1877) Øieblikket. Copenhagen: CA Reitzels Forlag.

Mark, B.G., et al. (2010) Climate change and tropical Andean glacier recession: evaluating hydrologic changes and livelihood vulnerability in the Cordillera Blanca, Peru. Annals of the Association of American Geographers, Special Edition on Climate Change,

Mayer, Enrique (2009) Cuentos feos de la reforma agraria peruana. Lima: IEP

Orlove, Ben, Ellen Wiegandt & Brian H. Luckman, eds. (2008), Introduction, in Darkening Peaks. Glacier Retreat, Science and Society, Berkeley: University of California Press.

Pærregaard, Karsten (1997) Linking separate worlds: Urban migrants and rural lives in Peru: Berg Publishers.

Ricoeur, Paul 1984. Time and Narrative. Transl. by K. MacLaughlin & D. Pelleauer. Chicago: University of Chicago Press.

Risør, Helene (2010) Violent Closures and New Openings. Civil Insecurity, Citizens and State in El Alto, Bolivia. PhD-Thesis, Department of Anthropology, University of Copenhagen

Robbins, Joel (2004) The globalization of Pentecostal and charismatic Christianity. Annual Review of Anthropology:117-143.

Strathern, Marilyn (2005) "Robust Knowledge and Fragile Futures" in Aihwa Ong and Stephen J. Collier (eds.) Global Assemblages: Technology, Politics and Ethics as Anthropological Problems. Oxford: Basil Blackwell, pp. 464-80.

Taylor, Charles 2004. Modern Social Imaginaries. Durham & London: Duke University Press

Turnbull, David (2004) "Narrative Traditions of Space, Time and Trust in Court: Terra Nullius, 'Wandering', the Yorta Yorta Title Claim, and the Hindmarsh Island Bridge Controversy" in Gary Edmond (ed.) Expertise in Regulation and Law. London: Ashgate, pp. 166-83.

Walley, Christine (2004) Rough Waters: Nature and Development in an African Marine Park. Princeton: Princeton University Press

The Himalayan Vertical Archipelago: Climate Change, Glacial Lake Insecurity, and Institutional Capacity in the Khumbu Himalaya

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One way to better understand the ways in which climate change is currently affecting the Himalayan region is by focusing on the vertical distribution of the complex natural and social transformations that are occurring across the steep gradients of the range. Interdisciplinary research from the Andes and Himalayas focusing on the common relationships between natural and human systems in mountainous areas has long argued that these landscapes often resemble vertical "archipelagos" that are defined by unique "zones" of bioclimate and human activities (Murra 1972; Guillet 1983). According to the "verticalists," human civilizations have historically sought to utilize as many bioclimatic zones as possible by linking them together through institutional networks of resource management, production, and exchange. While the larger verticality hypothesis on the origins of mountain civilizations is likely to remain unsettled, the tiered archipelago model that emerged from these debates has proven to be a useful conceptual framework that might be utilized in a more limited and contemporaneous fashion to provide insights into the distribution of bioclimatic zones across the Khumbu region of the Nepalese Himalayas, how they are linked together by networks of social institutions, and the ways in which current patterns of climate change are differentially affecting vertical zones and human vulnerability to glacial lake hazards.

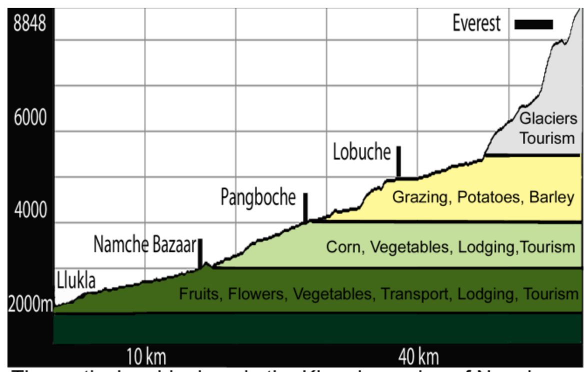
The Himalayan Vertical Archipelago


Llotse South Face-8515m

The Nepali Himalaya contains some of the most precipitous terrestrial escarpments on the planet. From the Terai outer plains, the Southern slope of the range soars more than 8,500 meters in as few as 100 kilometers. The Khumbu area, which is located in the upper Dudh Koshi river basin and contains several of the highest peaks on the planet – including Mount Everest (8848m) and Llotse (8516m) – is even steeper as it ascends nearly 6,000 meters in just 60 kilometers. The extreme height of the range, its altitudinal gradient, and the monsoon precipitation regime that feeds the 482 square kilometers of glaciers in the upper basin (~10% of Nepal's glacial coverage), have created niches for 11 different bioclimatic zones, which have disproportionately concentrated species biodiversity along the sharp uplift of the range between 1,000 and 3,000 meters. Nepal is home to more than 1,988 animal species and 6,280 plant species (ICIMOD 2007b).

The social systems spread across these bioclimatic zones are differentiated as well and communities generally decrease in size as elevation increases. Along the range and at the base of the highest peaks in the world are the 278 glaciers that provide meltwater for irrigation, hydropower, and human and animal consumption at lower elevations (ICIMOD 2007a). Beneath the glaciers, meltwater and precipitation supports wetlands where yaks and cows are pastured. Below the high grazing areas, households cultivate high elevation crops such as corn, barley, and potatoes. Approximately 80% of households are engaged in smallholder agricultural and livestock production. Beginning in 1953, when Mt. Everest was first summited, the frozen upper zone of the Himalayan archipelago was incorporated into social networks of production and exchange through rapidly increasing mountain tourism, trekking, and climbing activities. Because there are no roads above 2,000 meters, local Sherpa populations and livestock are also the physical links between the airstrip at Llukla and these new zones of economic production and consumption. Tourism has increased rapidly over the past several decades and the communities of the region have become very dependent on income from this sector. Tourism-related livelihood income generation has also come to affect other livelihood production activities, such as agricultural, because crops are often harvested to accommodate the main expedition season, which begins in October and continues until the monsoon rains begin in April or May.

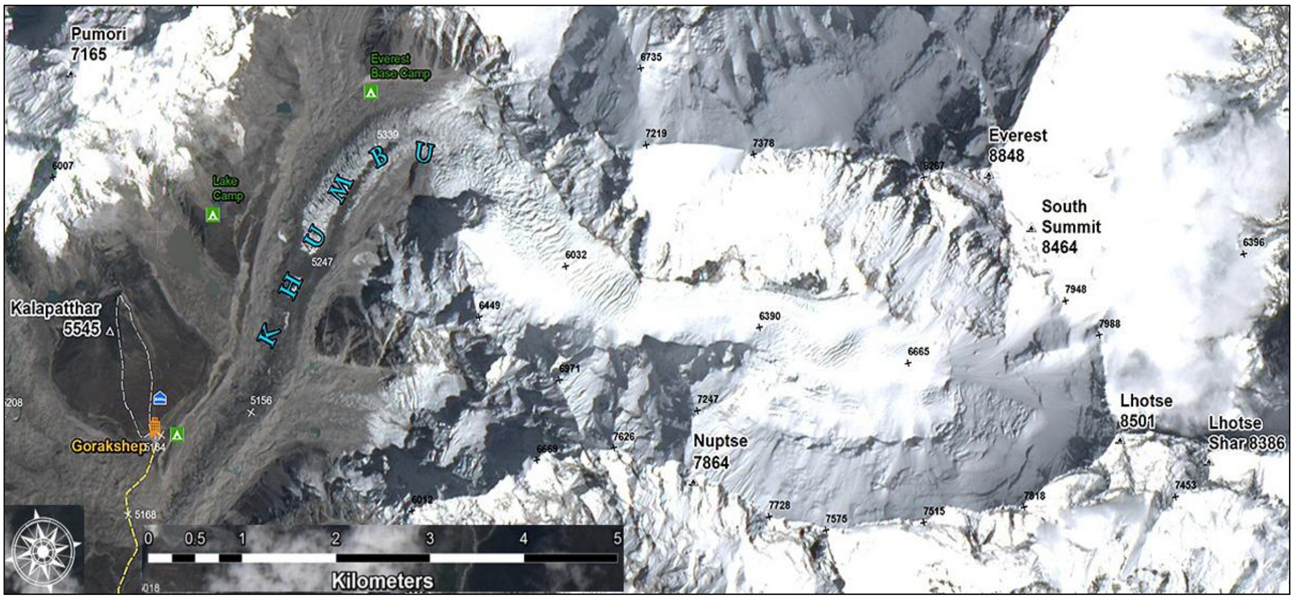
The social institutions that link human activities across the diverse bioclimatic zones of the region are comprised of several predominant political, economic, and cultural networks. These linkages consist of patterns of economic production, social reproduction, and natural resource management. Perhaps the most pervasive set of networks are economic exchange relationships that link households across elevations and to larger markets through subsistence activities such as agriculture, livestock, and labor. This dense web of relationships allows for the provision of human necessities such as food, water, shelter. However, the productivity of these webs is mostly insufficient at higher elevations as poverty rates are pervasive. Linkages between these economic networks and natural resource management activities are largely focused on short-term resource maximization strategies and natural resource exploitation, rather than longer-term strategies with broader management objectives. However, small community-scale collaborative management activities related to activities such as irrigation, potable water, and pasture management have been successfully developed in many places.



The vertical archipelago in the Khumbu region of Nepal

Politically, Nepal was long isolated from outside influences by a royal monarchy for much of its history. However, beginning in 1959, successive waves of instability and political unrest radically altered this order. Since then, political changes in the country included the return of the monarchy, the failure of several different democratic administrations, and then a 12-year civil war that led to the creation of several revolutionary or insurgent movements. In 2007, the Communist Party of Nepal transformed the national government yet again into a democratic republic. One legacy of the near-constant state of violence and political upheaval in the country over the past 50 years is that political governance structures and relationships of legitimacy and trust throughout the country have been either weakened or completely destroyed. Perhaps the most severely affected political networks have been those between the capital, Kathmandu, and ethnically diverse populations at higher elevations. The failure of these political networks has had significant negative impacts on the country's economy and infrastructure and, while political instability has lessened over the past few years, new networks have yet to be fully reformed. Like many post-conflict societies, the failure of state institutions of control in Nepal has also been accompanied by the weakening of national systems of natural resource management and control. However, while this has been the case for much of the country, large-scale conservation activities in Khumbu region have remained intact. This appears to be largely the result of two key factors. First, because the region is host to several of the world's tallest mountains, it has become a location of global significance and new transnational political and economic networks have been established with the region. These new linkages have also been accompanied by a significant influx of bilateral and multilateral aid and assistance programs and the long-term presence of professional staff from a variety of international agencies, and have significantly affected natural resource management activities in the Khumbu, largely through the creation of Sagarmatha National Park in 1976, and its designation as a Natural World Heritage Site in 1979.

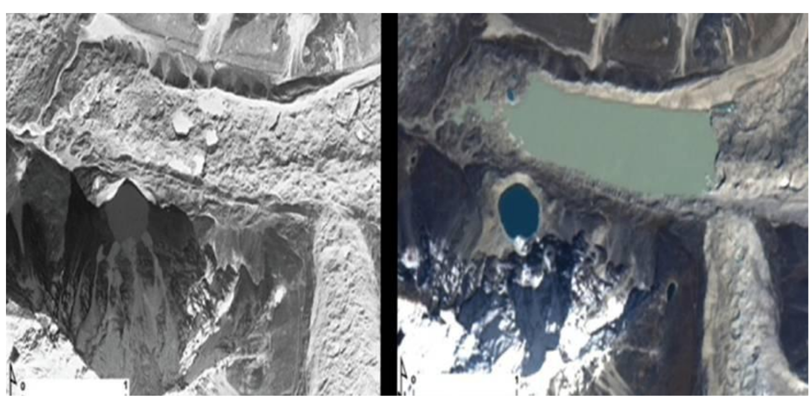
The other major factor influencing conservation activities in the Khumbu, which perhaps explains why the impacts of the Maoist insurgency were not as significant in the region are the strong Sherpa cultural and ethnic networks and institutions that link human activities across the vertical axis of the range. After migrating to Nepal several centuries ago, the Sherpa population (est. pop. 145,622 in 2001) became the predominant ethnic group in the Khumbu above the community of Llukla (Pangboche is the oldest Sherpa community in Nepal and incidentally, the second largest concentration of Sherpas outside of the Khumbu is in New York City). During the past 50 years of political instability, when many national political networks disappeared in the region, they were frequently replaced by kinship-based Sherpa networks. The replacement of state networks was further facilitated by international conservation agencies when Sagarmatha National Park (see below) was created, since only local Sherpa populations can own land in the park. In addition, the rapid growth of the tourism industry, and the fact that Sherpas are world-renowned for their high elevation endurance, has allowed kinship-based Sherpa networks to control the provision of lodging, food, transportation, and expedition support that links tourists to the highest elevations on the planet.



The Mount Everest Region of Sagarmatha National Park (Source: NASA 2010 EO-1 Image; GIS by author)

Climate Change and Glacial Lake Insecurity in the Khumbu

Over the past several decades, global climate change has spurred a set of complex set of inter-related natural transformations across the Nepal Himalayas and the Khumbu region. According to recent research, air temperature across most of the region increased significantly over the past century and the rate of warming has accelerated over the past few decades at a rate of .06 to 0.12°C/year (ICIMOD 2007a). Increases in temperature have been accompanied by decreasing trends in precipitation and reductions of total seasonal snowfall. The combined results of these changes have been consistent and pervasive reductions of glacial coverage in the region. Between 1960 and 2001, low elevation glaciers retreated across the Dudh Koshi basin at an average of 5 to 10 meters per year. This rate has been much higher in some instances and has also been accelerating. For example, the



Lake Imja-1964 (Corona) and 2010 (EO-1) Satellite Images average recession rate of the Imja glacier (see adjacent images) between 1960 and 2001 was 59 meters per year, but over the past half-decade it has been retreating an average of 74 meters per year. The cumulative range of retreat of glaciers between 1964 and 2001 across the entire Dudh Koshi basin was a minimum of 400 meters and a maximum of 2,340 meters. The magnitude of the associated volumetric reductions of glacial ice may never be known because comprehensive measurements were never completed before the glaciers began to recede.

One consequence of the rapid glacial retreat occurring across the region is that massive quantities of water have been released from the frozen heights of the Himalayan vertical archipelago, which has resulted in a number of significant new climate change-related threats to human vulnerability. The most significant new vector of vulnerability has been the creation of a large number of new glacial lakes. Since 1960, more than 35 new moraine-dammed or supraglacial lakes have appeared in the watershed and the overall area of moraine-dammed lakes has increased 217%. Because the moraines holding these massive quantities of water are loosely consolidated and often partially frozen, they are also inherently unstable and have a very high likelihood of creating glacial outburst floods (GLOFS) that would have disastrous cascading effects on downstream natural environments and human settlements. While only 12 instances of GLOFs have ever been recorded for the entire country (one of which occurred in the Khumbu in 1985), the Dudh Koshi basin now contains at least 12 glacier lakes that have been classified as potentially dangerous. Half of these 12 lakes are growing rapidly and are expected to eventually breach their moraines (Ibid.).

The fact that a number of new lakes have appeared beneath the glaciers of the Khumbu region clearly illustrates that climate change-induced warming is altering glacial mass balance dynamics. That one or several of them, in the absence of any preventative action, will eventually breach their moraines and release massive quantities of water downstream is deeply alarming and should provide a compelling rationale for urgent mitigation efforts. However, while the risks associated with accelerating glacier retreat and increases in glacial lake hazards are rapidly increasing, the political, social, and cultural networks that currently exist in the region have little capacity to affect the increasing probability that (1) a GLOF will occur in the future, and (2) it will have disastrous consequences for human well-being downstream.

There at least are several reasons why the current constellation of networks and institutions that link the vertical archipelago of the region do not possess the necessary capacity to address these urgent challenges. This includes factors related to resource mobilization, legitimacy, technical capacity, and efficacy. First, the weakening of political networks due to civil upheaval in the country reduced the ability of the state to mobilize the necessary economic and technical resources. While some hazard assessment and risk reduction activities have been undertaken at a few lakes by the Nepali government (e.g. Imja Tsho and Dig Tsho), or were executed by international organizations and research teams (e.g. ICIMOD, TMI), thus far these efforts have been very limited due to resource availability and were temporally intermittent. Furthermore, the weakening of political institutions in the country has also eroded the legitimacy of state institutions to make claims as the exclusive arbiter of public welfare. Post-conflict societies like Nepal are often crippled by the lack of this legitimacy, which frequently limits the state's ability to enforce any activity that might incur social or economic consequences. Another reason is that the current economic and cultural networks that link the vertical structures of the Khumbu region are even less able than state institutions to address these challenges. For example, household or small-scale economic networks do not have the necessary spatial extent, and therefore the efficacy, to implement watershed-wide hazard management activities. Furthermore, Sherpa institutions, while very effective at managing economic resources and providing services to tourists, are even less capable than state institutions at leveraging the necessary resources, technical capacity, and legitimacy to accomplish hazards management activities.

Finally, and to further exacerbate the challenges facing local populations in the Khumbu, the mere absence of any legitimate and reliable institutional capacity to address the increasing likelihood that a disastrous GLOF will occur in the Khumbu in the near future is also a problem, primarily because of the uncertainty it creates. For example, if emergency monitoring systems were to be installed the region, and the organization responsible for their installation is not perceived as legitimate, local populations might simply ignore any warnings that are generated. In addition, if the emergency monitoring systems are not reliable, they might also induce "disaster fatigue" after the first one or two false alarms, and and ignored from that point onward. Furthermore, if the physical safety of the monitoring systems cannot be guaranteed, they might be stolen, which frequently occurs in high elevation settings across the planet. This lesson has already been illustrated in the region as the first emergency monitoring network that the national government installed was removed, disassembled, and then turned into pipe bombs and explosives by insurgents to further erode the legitimacy of the state during the recent civil war. Finally, and perhaps most importantly, the absence of this capacity can lead to widespread uncertainty, fear, misunderstanding, the manipulation or exploitation of fearful people, and social conflict. Currently, all of these instances have either occurred or the potential for them to occur is increasing throughout the region.

Fostering New Institutional Adaptive Capacity

The accelerating pace and scale of environmental changes occurring in the Khumbu region of Nepal are not only compelling testimonials from the icy edge of climate change, they also pose clear and imminent threats to human welfare and safety across the Himalayan vertical archipelago. While climate change is transforming the region, and will very likely accelerate during the next several decades, its consequences do not need to inexorably lead to unavoidable natural disasters and widespread suffering and human tragedy. On the contrary, many of the worst-case scenarios might be avoided through the creation of new hazard management institutions to enhance glacier monitoring and evaluation activities and foster more effective natural resource management activities. The creation of new institutional capacities is therefore a critical necessity that needs to be accomplished immediately. Below are several considerations that seek to inform any effort to enhance institutional adaptive capacity and long-term resilience.

- Doing Nothing Is Not an Option. As several lake hazards studies have illustrated, in the absence of any effective hazards management activities, one or several lakes in the region will create GLOF events. In the worst case scenario, this could result in significant human mortality, widespread damage to agricultural land and crops, livestock losses, and the destruction of critical infrastructure. In addition, the current absence of any effective institutional capacity has the potential to further exacerbate uncertainty and social conflict in the region. Furthermore, as recent debates surrounding the Kyoto Protocol have illustrated, climate change has now become inextricably intertwined with larger questions of social equity and environmental justice, as it is disproportionately affecting the most vulnerable populations that have historically had the least intensive carbon lifestyles. The Khumbu region is a harbinger of these debates because climate change is rapidly transforming the region and is creating a number of significant risks for local populations. In fact, the high mountain glaciers are where many of the effects of climate change are the most advanced and, therefore, any decision or attempts to avoid larger questions of both equity and mitigation in the Khumbu will not only have highly probable and very tragic human consequences, but significant social and political repercussions through the precedents that are established as well.
- Foster Hybrid Institutions. Mitigation efforts should build upon the diverse array of cultural, economic, and political networks that are present in the region and foster the creation of new hybrid institutions that include state, private, and civil society actors. In addition, because political relations of legitimacy and efficacy are currently very difficult to rebuild, but are critically important, capacity building efforts should also emphasize the need for legitimacy, efficacy, and enforcement.
- Enhance Adaptive Capacity. Because climate change is likely to accelerate over the next century, and the impacts of these changes are highly likely to be unexpected and diverse, new hazards management institutions and systems should be designed to provide maximum flexibility for monitoring, assessment, and mitigation efforts. In addition, maximizing adaptive capacity will also enhance the long-term resilience of these institutions as well as the security and reliability of hazards monitoring systems.
- Work at the watershed scale. Any mitigation efforts to enhance adaptive capacity must also be "scaled" appropriately such that they are spatially comprehensive and consistently deployed. In

the Khumbu region, this will require concerted hazards monitoring and evaluation activities across the entire basin, the development of effective evaluation procedures, and the creation of a reliable emergency warning system. Scaling up to the watershed can also enhance the legitimacy hazards institutions.

- Plan for Disaster Assessment and Recovery. Finally, although mitigation activities should primarily be fostered to prevent the future occurrences of GLOFs and other glacier-related hazards, mitigation, and planning efforts should also focus on the creation of disaster assessment and recovery capabilities. In doing so, this will enhance the long-term resilience of hazards management institutions and address the fact that although we have enhanced our understanding of the enormous vulnerabilities that climate change is creating in the region, a high degree of uncertainty about future events is likely to be a permanent challenge.

Literature

Guillet, D. (1983). "Toward a Cultural Ecology of Mountains: The Central Andes and the Himalayas Compared." *Current Anthropology* 24(5): 561.

ICIMOD (2007a). *Impact of Climate Change on Himalayan Glaciers and Glacial Lakes: Case Studies of GLOF and Associated Hazards in Nepal and Bhutan*. Kathmandu, International Center for Interated Mountain Development.

ICIMOD (2007b). *Nepal Biodiversity Resource Book*. Kathmandu, International Center for Integrated Mountain Development.

Murra, J. (1972). The Vertical Control of Ecological Zones in Andean Societies. Spain, Universidad Hermilio Valdizán.

Adapting Resource Governance to Global Change: Theoretical Considerations

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Adaptation is nothing new. Both social and ecological communities have long modified their behavior in response to shifting climatic and cultural conditions, among other factors. Elements of adaptation that have changed markedly in the modern context, however, are the pace and scale of transformations linked to both climate change and economic globalization as well as the ways in which these processes converge to impact the vulnerability and adaptive capacities of a wide range of social and ecological systems (SES) (Liverman 1990, Eakin 2006, Leichenko and O'Brien 2008). Both separately and in conjunction with one another, climate change and economic globalization are generating new supply and demand-side pressures on natural resources that increasingly link stakeholders at spatial scales from the local to the global as a result of functional interdependencies in resource-use systems (Arnell 1999, Bebbington and Bury 2009, Brondizio, Ostrom and Young 2009). These interdependencies create both opportunities and challenges for the use and management of resources and are forcing institutions to respond rapidly to shifting and uncertain conditions and to develop linkages between previously unconnected or poorly articulated actors in resource governance sectors (Young et al. 2006, Pahl-Wostl 2009).

Given the growing recognition of the scope of global change processes (IPCC 2007a, IPCC 2007b), a great deal of recent research critically considers the concepts of vulnerability and adaptive capacity and, in some cases, has looked specifically at how these factors impact resource governance (Adger 2006, Brooks, Adger and Kelly 2005, Engle and Lemos 2009, Nelson, Adger and Brown 2007, Smit and Wandel 2006). Definitions, determinants, and analytical frameworks abound, their diversity generating both complementary concepts and abiding problems of comparability (Brooks 2003, Füssel 2007, Polsky, Neff and Yarnal 2007, Turner et al. 2003). On one hand, much of this scholarship is increasingly attentive to the complexities of cross-scalar linkages and to the hybridity of SES, stressing the need for careful attention to social, political economic, technological, and biophysical conditions that interact at multiple levels (Adger, Brown and Tompkins 2005, Cash et al. 2006, Young et al. 2006). On the other hand, recent research points to significant lacunae in the literature, suggesting the need for more thorough economic analysis, greater attention to the agency of local people, and empirical examples of how diverse factors come together to shape adaptation decision-making and particular modes of governance (Carr 2008, Liverman 2008, Tschakert 2007). In any case, the need for innovative means for transferring scholarly research results on resource governance to the policy sector and to the general public is both urgent and daunting, especially given the current political manipulation of science.

A particularly important development in the recent research on vulnerability and adaptation has been heightened attention to the ways in which human value systems and the power of certain actors to impose their preferences on others create social limits to the adaptation process (Nelson et al. 2007, Adger et al. 2009, O'Brien 2009). As Adger et al. state, "Values translate into action because they frame how societies develop rules and institutions to govern risk, and to manage social change and the allocation of scarce resources" (2009: 338). This emphasis on values and power suggests a need to understand more fully how socio-cultural relations, economic and market forces, technological and scientific discourses, and the legal and political structures in which an array of stakeholders manage resources all affect how societies adapt to linked processes of global change at multiple scales, creating both "winners and losers" in the process (Adger et al. 2005, Forsyth 2003, O Brien and Leichenko 2003).

One way in which scholars have approached this complex conceptual landscape is through a focus on institutions and their linkages across scales. Much of this research explores how values and power are expressed and negotiated through institutional mechanisms and their interactions at different levels in the resource use system (conceptualized as "social capital" or "actor networks," among other definitions) and identifies new hybrid forms of governance that are emerging from these interactions (Agrawal 2008, Brondizio et al. 2009, Eakin and Lemos 2009, Lemos and Agrawal 2006).

While acknowledging the theoretical developments outlined above, it is necessary to emphasize that, although careful attention to institutional landscapes and the underlying values that shape resource governance is fundamental, the role of biophysical conditions in enabling and constraining human appropriation and use of natural resources is also critical. This point is not meant to promote environmental determinism but rather to affirm Young et al.'s suggestion that "biophysical systems need to be seen as interacting with social and economic systems, while social processes like globalization need to be seen as being coupled to the dynamics and constraints imposed by biophysical systems" (2006:314). This perspective may strike many readers as simple common sense, yet there remains a surprising dearth of detailed analyses focused on the coupled natural-human systems that shape resource governance and adaptation to global change in general. Young et al., among many other scholars, suggest that addressing this research gap requires interdisciplinary research approaches capable of capturing the multiple impacts of converging processes of global change on SES. Clearly, much of the promise of applied research initiatives, such as the Imja Lake Hazards Workshop and the Global Glacial Lake Partnership, lies in their ability to foster such interdisciplinary research approaches and to disseminate meaningful findings to policy-makers and the public in general.

References:

Adger, W., K. Brown & E. Tompkins (2005) The political economy of cross-scale networks in resource co-management. *Ecology and Society,* 10**,** 9.

Adger, W., S. Dessai, M. Goulden, M. Hulme, I. Lorenzoni, D. Nelson, L. Naess, J. Wolf & A. Wreford (2009) Are there social limits to adaptation to climate change? *Climatic Change,* 93**,** 335-354.

Adger, W. N. (2006) Vulnerability. *Global Environmental Change,* 16**,** 268-281.

Agrawal, A. 2008. The role of local institutions in adaptation to climate change. Washington DC: World Bank.

Arnell, N. (1999) Climate change and global water resources. *Global Environmental Change,* 9**,** S31-S49.

Bebbington, A. & J. Bury (2009) Institutional challenges for mining and sustainability in Peru. *Proceedings of the National Academy of Sciences.*

Brondizio, E., E. Ostrom & O. Young (2009) Connectivity and the Governance of Multilevel Social-Ecological Systems: The Role of Social Capital. *Annual Review of Environment and Resources,* 34**,** 253-278.

Brooks, N. (2003) Vulnerability, risk and adaptation: A conceptual framework. *Tyndall Centre, University of East Anglia.*

Brooks, N., W. Adger & P. Kelly (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change Part A,* 15**,** 151-163.

Carr, E. (2008) Between structure and agency: Livelihoods and adaptation in Ghana's Central Region. *Global Environmental Change,* 18**,** 689-699.

Cash, D., W. Adger, F. Berkes, P. Garden, L. Lebel, P. Olsson, L. Pritchard & O. Young (2006) Scale and cross-scale dynamics: governance and information in a multilevel world. *Ecology and Society,* 11**,** 8.

Eakin, H. (2006) Weathering risk in rural Mexico. climatic, institutional, and economic change.

Eakin, H. & M. Lemos (2009) Institutions and change: The challenge of building adaptive capacity in Latin America. *Global Environmental Change.*

Engle, N. & M. Lemos (2009) Unpacking governance: Building adaptive capacity to climate change of river basins in Brazil. *Global Environmental Change*.

Forsyth, T. 2003. *Critical political ecology: the politics of environmental science*. Routledge.

Füssel, H. (2007) Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change,* 17, 155-167.

IPCC (2007a) Climate Change 2007: Impacts, Adaptation and Vulnerability. *Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report*, 1000.

---. 2007b. Climate Change 2007: The Physical Science Basis., 996. Cambridge.

Leichenko, R. & K. O'Brien. 2008. *Double exposure: Global environmental change in an era of globalization*. Oxford Univ. Press.

Lemos, M. & A. Agrawal (2006) Environmental Governance. *Annual Review of Environmental Resources,* 31, 297-325.

Liverman, D. (1990) Drought impacts in Mexico: Climate, agriculture, technology, and land tenure in Sonora and Puebla. *Annals of the Association of American Geographers,* 80, 49-72.

--- (2008) Assessing impacts, adaptation and vulnerability: Reflections on the Working Group II Report of the Intergovernmental Panel on Climate Change. *Global Environmental Change,* 18, 4-7.

Nelson, D., W. Adger & K. Brown (2007) Adaptation to environmental change: contributions of a resilience framework.

O Brien, K. & R. Leichenko (2003) Winners and losers in the context of global change. *Annals of the Association of American Geographers,* 93, 89-103.

O'Brien, K. 2009. Do values subjectively define the limits to climate change adaptation? In *Adapting to Climate Change: Values, Thresholds, Governance,* eds. W. Adger, I. Lorenzoni & K. O Brien. Cambridge: Cambridge University Press.

Pahl-Wostl, C. (2009) A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change,* 19, 354-365.

Polsky, C., R. Neff & B. Yarnal (2007) Building comparable global change vulnerability assessments: The vulnerability scoping diagram. *Global Environmental Change,* 17, 472-485.

Smit, B. & J. Wandel (2006) Adaptation, adaptive capacity and vulnerability. *Global Environmental Change,* 16, 282-292.

Tschakert, P. (2007) Views from the vulnerable: Understanding climatic and other stressors in the Sahel. *Global Environmental Change,* 17, 381-396.

Turner, B. L., R. E. Kasperson, P. A. Matson, J. J. McCarthy, R. W. Corell, L. Christensen, N. Eckley, J. X. Kasperson, A. Luers, M. L. Martello, C. Polsky, A. Pulsipher & A. Schiller (2003) A Framework for Vulnerability Analysis in Sustainability Science. *Proceedings of the National Academy of Sciences of the United States of America,* 100, 8074-8079.

Young, O., F. Berkhout, G. Gallopin, M. Janssen, E. Ostrom & S. van der Leeuw (2006) The globalization of socio-ecological systems: an agenda for scientific research. *Global Environmental Change,* 16, 304-316.

Prioritizing Adaptation Investments for Development Impact

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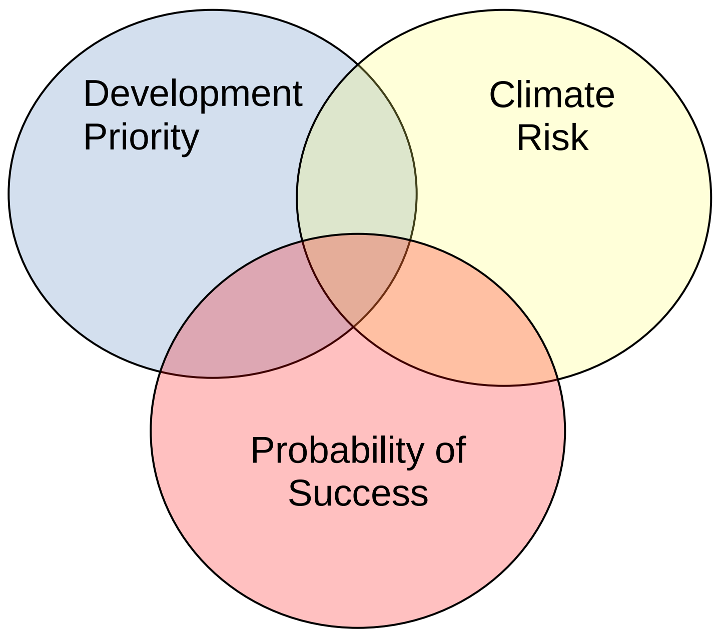
USAID began substantial investments in adaptation programming in 2010. Those with responsibility for turning funding into development action were faced with several challenges. The intent of the Adaptation funds is to help program planners understand the possible effects of climate change on development programs, and give them the tools to address negative impacts and design more robust programs. The challenge comes in trying to decide where to start.



At USAID, we want to find a balance between addressing severe climate risks, working in high-priority development sectors, and working on projects that will achieve their intended goals. We need to address climate risks; aligning them with important development sectors will help ensure our investments are relevant to the country we are assisting; considering the likelihood of success will help ensure that we maximize our investments.

USAID also wants to respond to the needs and wishes of our partners in developing countries. Many of them have developed their own development and adaptation plans. Least Developed Countries (LDCs) have developed National Adaptation Programs of Action (NAPAs) as part of the UNFCCC process. NAPAs were developed through a process of stakeholder engagement with the intent of identifying urgent adaptation needs in LDCs. While some were more inclusive than others, they all can serve as a starting point for prioritizing USAID investments. The UNFCCC National Communication process requires all member countries to report from time to time on their greenhouse gas emissions and on vulnerabilities to the impacts of climate change. Most developing countries are working on their second or third national communications. The CIA World Fact Book and World Bank documents, available on the web, are a quick source of information on the makeup of an economy. Many countries also have national development and sector plans, Poverty Reduction Strategy Papers, national adaptation plans, and other documents that can serve as a source of information on the goals and needs of the countries where USAID works.

USAID has developed a process for quickly prioritizing adaptation investments that draws on the plans and documents mentioned above, and engages stakeholders for further input. USAID developed and applied the process while designing a program in the East Caribbean, but the approach should work in most places.

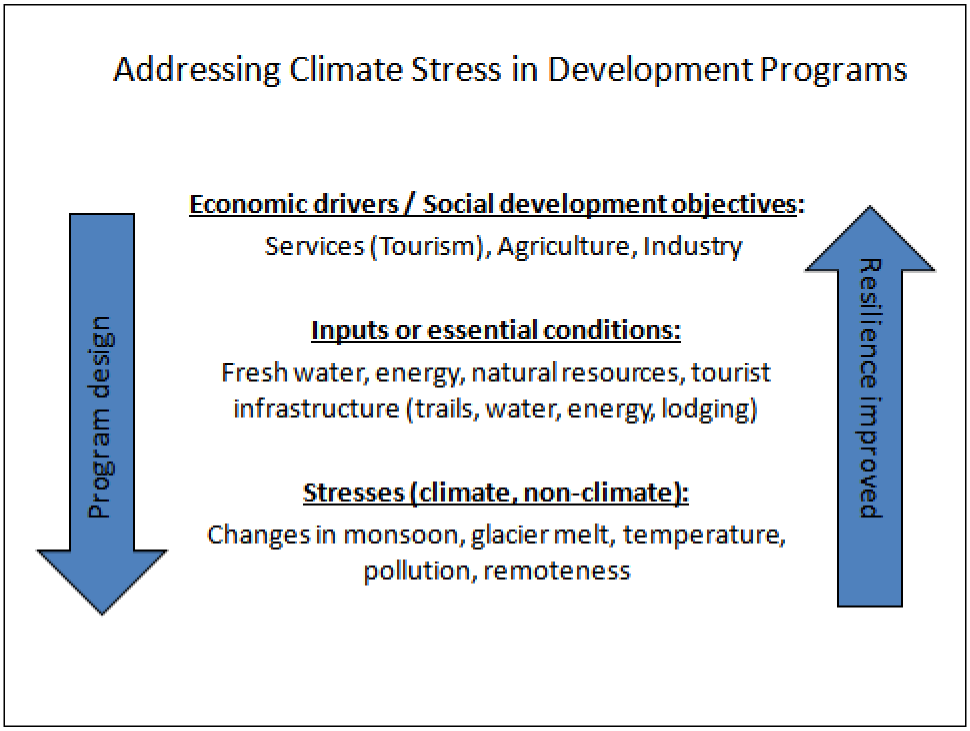
We begin by reviewing relevant national plans to identify needs and priorities. Next, we convene a workshop with participants drawn from government, the private sector, and non-governmental organizations. We ask participants to identify and discuss the key sectors of their country's economy or important development needs. This input is compared to findings from a review of strategy documents and differences discussed with participants to understand why priorities may have changed. It could be that priorities have changed, or it could be that something has happened to steer the discussion in a particular direction.

Once we had established economic sectors or development priorities to focus on, we asked participants to discuss conditions necessary to support those areas. What is necessary for a robust agriculture or tourism sector? Responses may range from healthy ecosystems to adequate water supplies, to good governance, robust infrastructure, a stable global economy, or limited corruption.

Next, we discuss stresses or impediments that could compromise the conditions necessary to achieve economic outcomes. We asked participants to discuss all stresses, climate and non-climate. Although many of the stresses may not be appropriate for a climate adaptation program, it is important to understand them for several reasons. First, if non-climate stresses far outweigh climate stresses in impeding a key economic area, reducing the climate stressor may do little to improve the overall outcome in that area. For example, changes in the monsoon in Nepal may shorten the post-monsoon tourist season, but the unrest from the Maoist insurgency of the last decade played a much bigger role in reducing tourist visits. Second, though climate funds might not be used to address non-climate stresses, other development assistance or host country resources might be. Reducing the impact of all the stresses will be important for achieving desired outcomes.

When USAID is designing a program using funds expressly intended for assisting with adaptation to climate change impacts, we ask participants to set aside non-climate stresses for the moment; other sources of funding would have to be found for those concerns. We ask that they consider which stresses, if alleviated, would offer the greatest improvement in achieving economic or development goals; where should we start to get the most "bang for the buck?"

Next, we solicit ideas for addressing the stresses. Participant input can provide insights on what will work in the local context and may offer information on what has or hasn't worked in the past. It will also help build a sense of ownership over whatever project follows. That ownership is important for project acceptability and for sustainability after the donor withdraws. Where USAID has applied this approach, we have gotten a rich array of ideas for implementation.



We did not use this process to design the project in Nepal. We had donors and implementing partners with an interest in glacier lakes, and Imja Lake was chosen as a representative lake that was relatively accessible to the expedition. Had we chosen to follow this process, some of the factors that might have come to light include: The services sector, including tourism, accounts for about half of Nepal's economy. Agriculture is second, accounting for about a third of GDP, according to the CIA World Fact Book. Sagarmatha (Everest) National Park is a major tourist attraction. The hazards of glacier lake outburst floods are identified as an important risk in the Nepal NAPA. A flood from Imja Lake would affect the trekking routes to Everest, Ama Dablam, and Island Peak, as well as the lodges and other infrastructure that support the trekkers. The valleys are also farmed for potatoes and cereals, providing food for tourists and residents and livelihoods for local farmers.

This process for identifying priority sectors and locations for adaptation work is appealing because it is simple and it engages host country counterparts in program design. It allows for the mining of local knowledge, experience, and interest for ideas about what might work and what might not. It can help identify what the impediments to growth are, be they information, technology, resources, or governance. It is important because it ensures that adaptation investments are firmly rooted in the development priorities of the host country.

Repeat Photography as a Tool in Detecting Landscape Change and Environmental Services in Sagarmatha (Mt. Everest) National Park, Nepal

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Many different techniques have been used in repeat photography since its development in the late nineteenth century (Boyer *et al.*, 2010). Although there has been a sustained effort to use this technique in documenting landscape change in geographical fieldwork, until recently few have used repeat photography for addressing questions concerning human geography and anthropology (Webb *et al.*, 2010). In this presentation, we present a novel application of repeat photography, using a diachronic photo-diary interviewing technique to examine the human experience and perception of contemporary landscape change, including perception of the degree of change, in relation to selected environmental services in the 1,398 km² Sagarmatha (Mt. Everest) National Park (SNP). These environmental services comprise water provision, food production, protection from natural hazards, tourism, and forests. The study is on-going and seeks to assess the impacts of contemporary landscape transformation on the aforementioned environmental services, and provide insight into the underlying drivers of change and its implications for the sustainable development of the region. In addition, we intend to generate a portfolio of adaptation strategies, specific to the park, and inform future management.

Change in many of the world's mountain regions is occurring at an accelerating pace (Körner & Ohsawa 2005). Recent small-scale analyses highlight the current landscape dynamics in the Himalayas, such as overexploitation, fragmentation, and degradation (Chaudhary et al., 2007). Over the coming decades, contemporary drivers of change such as land use, diffuse pollution, and demographic challengers are likely to be exacerbated by global climate change and associated socio-economic pressures (Müller-Böker et al., 2003). The underlying health of mountain ecosystems and their component habitats and biodiversity will therefore be subject to increasing pressures and choices (EEA, 2010), as will their ability to supply vital environmental services, such as protection against natural hazards, carbon sequestration and storage in biomass and soil, natural resources, tourism and recreation, freshwater, and business for thriving communities.

The Himalayas provide a wide range of environmental services, although these vary greatly at different spatial scales. Provisioning services come from agriculture and forestry systems; natural ecosystems; and rivers, which provide water and hydroelectricity. Regulating services relate particularly to climate, air quality, water flow, and minimization of natural hazards. Cultural services are associated with tourism, recreation, aesthetics, and locations of religious importance (MA, 2005; Rasul et al., 2011). Services of increasing importance relate particularly to water regulation, protection against natural hazards, tourism, recreation, and forests (EEA, 2010). It is important to recognize that mountain ecosystems are highly multi-functional. And, because benefits of services accrue to both mountain and lowland populations, the term "environmental services" is used in this presentation rather than "ecosystem services" in order to apply the concept to a wide range of application domains, also outside of a particular ecosystem.

Once, environmental services were taken for granted or, if perceived at all, were viewed as "gifts of nature." But by the beginning of the 21st Century, various forces – global and local; social, political and economic; climatic and ecological – have raised awareness of the degradation of mountain ecosystems, particularly in the Himalayas (Rasul at al., 2011). Although awareness of the role of the Himalayan mountain system has been increasing, there is a paucity of information available regarding the extent and impacts of landscape change on the provision of environmental services at the localized level. It is precisely at the local level that insights can facilitate a greater understanding of the different processes that influence the overall dynamics of environmental and landscape change. Given this, there is an urgent need to fill this gap to enable the development of more effective approaches for maintaining both thriving mountain environments and communities that can benefit from their services.

So, in the context of MtPAs, the challenge is to increase understanding and awareness that their protection and enhancement are relevant to people. For any effective relationship to exist between outside beneficiaries of the environmental services, and the mountain land-use systems and communities that generate the services, it is necessary to be explicit in defining what those functions are, and how best they can be measured and monitored. Therefore, the broad concept of environmental services as it is used today needs to be broken down into its constituent components in order to be clear on the cause-effect chains underlying the provision of these services. Appropriate incentives must be properly directed towards service providers and such mechanisms need to fit within the governance landscape of MtPAs. To meet this challenge, integrative research on environmental and landscape change provides us with a unique insight, encompassing as it does the totality of the physical setting and the human and natural driving forces which have shaped and changed them.

The use of repeat photography in this study began as an exercise in evaluating the method for additional insights it might provide in assessing the impacts of change on selected environmental services. Critical to this insight was the development of a stakeholder dialogue and the gathering of contextual material as an essential part of understanding the processes behind the patterns. This is especially important in the context of uncertainty concerning the extent of recent landscape dynamics in the Himalayas (Ives, 2004). From a collection of photographs taken by geographers, ex-national park wardens, and mountaineers, we selected for replication approximately 163 photographs, taken from 1950 – 1998 throughout the region. During two field visits, it was possible to relocate selected viewpoints in order to produce a set of replicates. This material allows a documentation of landscape changes over the last 55+ years, and serves as a basis for a qualitative assessment. In order to further quantify contemporary changes, the author is carrying out a comparative interpretation of aerial photographs and satellite imagery from mid-1970s (Garrard & Maharjan, in prep.).

Achieving the two main objectives of this year's fieldwork required: a) an in-depth analysis of perceptions of (past) landscape change in relation to selected environmental services, and b) spatially and demographically representative interviews to determine areas/elements of change, and to study differences in perception among social groups. This approach was carried out in the nine major year-round settlements in SNP. In each village we undertook semi-structured in-depth interviews (including many other discussions with local stakeholders) using a diachronic photo-diary in conjunction with ArcGIS scanned and georeferenced land cover topographical maps from 2006 and 2008 (ranging in scale from 1:1,250 - 1:10,000). As for the selection of the interviewees, the approach was to find contrast relevant to the objectives of the study. In the 46 interviews to date, all but one were recorded, translated, and transcribed from Sherpa into English and analysed according to qualitative content analysis.

The visualizations of the matched pairs of photographs presented as a diachronic photo-diary were of key importance. The interviewees were asked to rank perception of change on a 7-point scale from -3 = "negative change" to +3 = "positive change" as we systematically went through selected environmental services. In addition, interviewees were asked to sketch their local surroundings on high resolution maps, highlighting major landmarks and locations of key resources (water, food; fuel wood, timber, fodder, medicinal plants). Preliminary results not only provide insight into the perception and degree of change in relation to specific environmental services, but also outline the demand for services among demographic groups and in different regions of SNP. Such results highlight areas where a clearly articulate concept of environmental services can provide important support for helping meet conservation objectives, while ensuring the sustainable development of the region.

In summary: The research approach revealed a variety of complex conditions and change in the region, particularly with regard to the aforementioned environmental services. The experience of conducting the methodology also offered a chance to discover how Khumbu Sherpas perceive environmental change, and to explore their values and the disjuncture that sometimes occurs between perceptions and conditions. This is in a region with UNESCO World Heritage status, where local livelihood strategies primarily depend on tourism, subsistence farming, animal husbandry, and forest use. The field encounters proved to be an invigorating and insightful experience, and provided contextual information on the driving forces shaping environmental change. It also confirmed the important role of using an integrative approach in examining both the actual and perceived environmental and landscape change within the field of land change science. After all, as people interact with and impact the biophysical world, what we do has a lot to do with how we perceive the world (Lowenthal, 1996).

References

Boyer, D. E., R. H. Webb, and R. M. Turner. 2010. *Techniques of Matching and Archiving Repeat Photography Used in the Desert Laboratory Collection*. In: Webb et al., (eds) Repeat Photography: Methods and Applications in the Natural Sciences. Washington, D. C.: Island Press.

Chaudhary, R. P., Aase, T.H., Vetaas, O.R and Subbedi, B.P, 2007. (eds). Local effects of Global Changes in the Himalayas: Manang, Nepal. Tribhuvan University, Nepal and University of Bergen, Norway.

EEA (European Environmental Agency). 2010. Europe`s ecological backbone: recognising the true value of our mountains. Synthesis. Copenhagen.

Garrard, R., and G. R. Maharjan (in prep.) Land use dynamics and landscape change patterns in Sagarmatha National Park and Buffer Zone.

Ives, J. D. (2004): Himalayan Perceptions. Environmental change and the well-being of mountain peoples. Routledge, Abingdon.

Körner, C. and M. Ohsawa (Coordinating Lead Authors). 2005. Mountain systems. Chapter 24, In R. Hassan et al. (eds.) Ecosystems and Human Well-being: Current State and Trends, Volume 1, Island Press, Washington DC: pp 681-716.

Lowenthal, D. 1996. *Possessed by the past*. New York: Free Press.

MA (Millennium Ecosystem Assessment). 2005. Ecosystems and Human Well-Being. Synthesis. Washington, D. C.: Island Press.

Müller-Böker, U., Haeberli, W., Elsasser, H., Brassel, K., Itten, K., Schmidt, M.W.I. & Weibel, R. 2003. The Earth in Accelerated Change: Living Space in the 21st Century. Divergence and Convergence in Geography - Approaches and Perspectives at the Geographic Institute of the University of Zurich. Geographica Helvetica, 58 (3): 184-196.

Rasul, G., G, Chettri, N, and Sharma, E. 2011. Framework for valuing ecosystem services in the Himalayas. Kathmandu: ICIMOD Technical report.

Webb, R. H., D. E. Boyer, and R. M. Turner. 2010. (Editors) Repeat Photography: Methods and Applications in the Natural Sciences. Washington, D. C.: Island Press.

Climate Change, GLOF Risk and Glacial Lake Monitoring in Cordillera Apolobamba, Bolivia

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Introduction

I would like to start with three introductory considerations, in order to put the issue of glacial lake hazards in the Apolobamba mountain range in Bolivia into the wider context of the threat that global climate change poses to humanity.

I - Rapid retreat of mountain glaciers is the most visible sign of global warming.

II - What is happening with glaciers worldwide is probably also happening – silently and largely invisible to the majority of the people – to the ecosystems around the world.

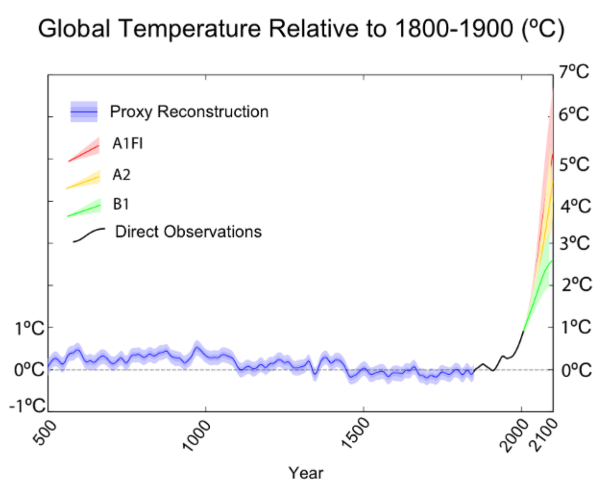
III - Given the present rate of climate change, in 20 years´ time the world is likely to look very different than what we can now imagine.

Global climate change

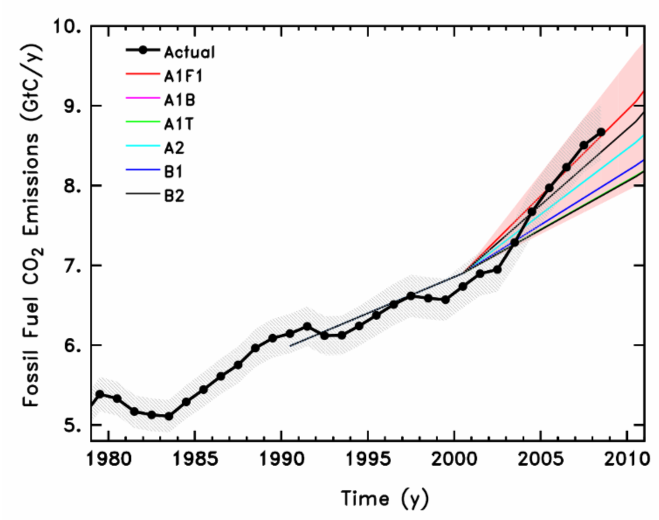
Climate change driven largely by anthropogenic activity is a fact and its consequences are already felt very clearly in Bolivian mountain areas. What scientists are debating today is the velocity and the magnitude of the impacts of climate change, as well as possible adaptation measures.

The United Nations Climate Change Convention (UNFCCC) calls for limiting global warming to levels that **do not interfere dangerously** with the global climate system. On this basis, a political consensus has emerged that 2°C should be considered as a limit, but no binding agreement has been reached yet. At the same time, scientist have alerted that keeping global warming below 2° is virtually impossible, among other things because of warming already committed by past emissions ("warming in the pipeline"), and that a global temperature increase by 4° C seemed a much more likely scenario.

This view is strengthened by a look at the Intergovernmental Panel on Climate Change (IPCC)´s emission scenarios and the current course of global CO_2 emissions:



Graphic 1: Global Temperature 500 – 2100 (IPCC 2001)



Graphic 2: Global CO_2 Emissions from Fossil Fuels

What are the consequences for Bolivian glaciers?

Bolivia is home to around 20% of the world´s tropical glacier area, while glaciers in Peru make up about 70%, Ecuador and Columbia around 4%, and Africa and Asia less than 1%. Glaciers are found mainly in the Eastern Cordillera, with only a very few and minor glaciers still existing in the Western Cordillera on the Chilean border. The total area covered with glaciers in Bolivia at the end of the 1980s has been calculated to be 566 km² by German geographer Ekkehard Jordan (Jordan 1991, WGMS 2008).

Photo 1: Receding tongue of Zongo Glacier on Huayna Potosí mountain with recently formed glacial lake, Cordillera Real, Bolivia
Photo credit: Dirk Hoffmann

As in most other parts of the world, rapid retreat of mountain glaciers has set in at the beginning of the 1980s, with another increase during the last 10-15 years (Hoffmann 2008). It can be safely assumed that a large number of the smaller and low-lying glaciers, which make up more than three quarters of all Bolivian glaciers, have disappeared over the last two decades.

Photogrammetric measurements realized by a French-Bolivian research team determined the volume and area changes of 21 glaciers in the Cordillera Real between 1963 and 2006. From this relationship, the ice volume loss of 376 glaciers has been assessed in this region. The results show that these glaciers lost 43% of their volume and 48% of their surface area between 1975 and 2006 (Soruco 2009). Considering that this data is now already five years old and that melting conditions should not have differed widely in the other Bolivian mountain ranges, we can deduce that the country has suffered a reduction of 50 % in glacier surface area and volume over the last 35 years. This data is corroborated by Rodrigo Tarquino for the Apolobamba mountain range (Tarquino & Flores 2011).

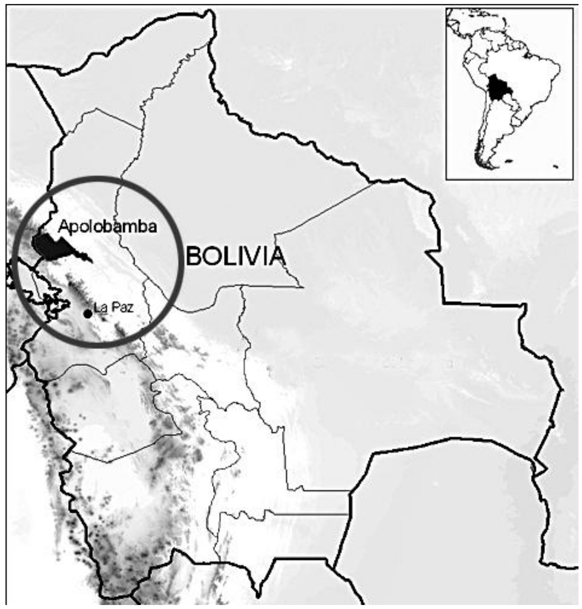
Photos 2 and 3: Rapid glacier retreat at Moro Kholla glacial lake, Cordillera Real. Left photo taken in March 2007, photo on the right taken in October 2009. Photo credit: Dirk Hoffmann

Formation of glacial lakes and GLOF hazards in the *Cordillera Apolobamba*

As glaciers have been receding, in many places small- and medium-sized glacial lakes have formed at the glacier tongue. This recent forming of glacial lakes in the Andes dates from the end of the Little Ice Age (1550-1850), but has increased sharply in the 1980s. Many of these lakes are geologically unstable, only contained by loose moraine debris. Thus, they pose a significant hazard to human life, settlements, and infrastructure located below (Hoffmann 2010b).

According to current revised climate change scenarios, a temperature increase of more than 6°C is expected to occur at altitudes higher than 5,000 m a.s.l. during the 21st century (IPCC 2007, Hoffmann & Weggenmann 2011). Such an increase will most likely cause the disappearance of the majority of tropical glaciers in Bolivia's *Cordillera Oriental* before the middle of this century, giving way to the formation of even more glacial lakes.

Up until recently, GLOFs have only been reported from Peru (e.g. Huaráz, 1941), the Himalayas, and other high mountain regions of the world, but the phenomenon had been unknown within the country. Then, a first documented case in Bolivia occurred in the Keara watershed in the *Cordillera Apolobamba* in November 2009.



Graphic 3: Map of Bolivia indicating Apolobamba

The *Cordillera Apolobamba* holds the northernmost glaciated area in area in Bolivia, with various peaks higher than 5,500 m and is located about 250 km northwest of La Paz and north of Lake Titicaca. On a global count, the Apolobamba mountain range accounts for about 7.5% of the world's tropical glaciers. Yet, there is almost no documentation available on glacial retreat. It is the northernmost part of the Eastern branch of the Andean *Cordillera* in Bolivia, about 120 km long and bordering with Peru. Its geographical setting makes the Apolobamba mountain range one of the least explored and least accessible mountain ranges in the Andes.

The Keara GLOF incident

On November 3, 2009 shortly before midday, the peasants of Keara village were completely surprised by a sudden and huge rush of water sweeping down the Keara valley on the Eastern slopes of the Andes. Even when the water masses subsided, they were still left puzzled as to what had happened. What they could see clearly, however, was the damage that had been done. Fortunately, there were no personal damages, but some livestock drowned, fields were devastated and 6 km of dirt road completely washed away, leaving the village incommunicado for several months.

Photo 4: Satellite image showing the glacial dammed lake above the Keara valley (long) before its outbreak on 3 November 2009
Photo credit: google.earth, August 4, 2005

Photo 5: The breach in the moraine below the glacier
Photo credit: Martín Apaza Ticona

Photo 6: Villagers inspecting damages, dead livestock
Photo credit: Martín Apaza Ticona

Apolobamba glacier lake inventory

In the wake of this local disaster it was possible to find a way to take a more systematic look at glacial lakes in the Apolobamba region. German geologist Daniel Weggenmann of Heidelberg University decided to do his thesis on this subject. Following the methodology developed by Christian Huggel (Huggel 2004), Weggenmann went to work. Using easily (and freely) available satellite images in a first step, an overview of all existing lakes in the Cordillera Apolobamba was produced. Next came the determination of age, size, volume, and growth rates of those lakes, followed by a determination of the material of the dams, the lake distance to glaciers as well as settlements and infrastructure down valley. On the basis of all those criteria a classification for all lakes according to the risk potential was possible, singling out the most dangerous ones. The last step was a field visit to some of the selected glacial lakes to get a first-hand view of the real conditions.

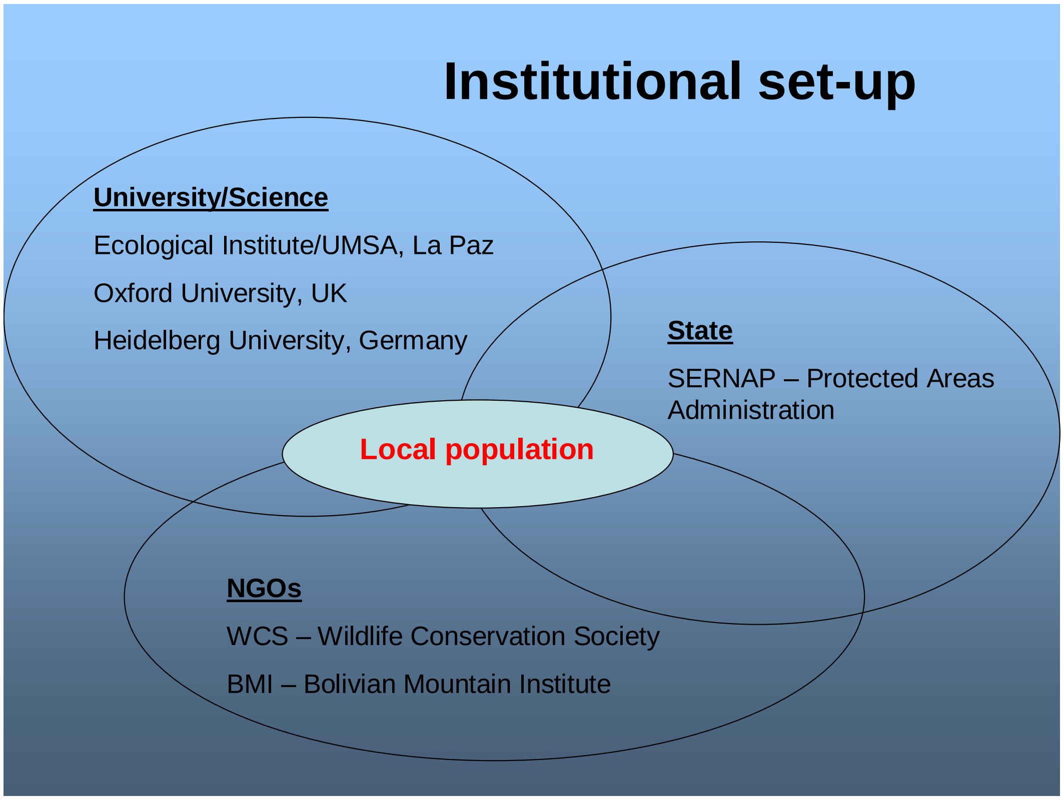
Graphic 4: The results of this glacier lake inventory, the first ever to have been realized in Bolivia, show that from 1986 – 2008 the number of contemporary glacier lakes went up from 174 to 216. Total lake area grew by approximately 2.5 km². The inventory has all information integrated in a GIS data base and includes recommendations for future monitoring of the potentially most dangerous lakes (Weggenmann 2011).

Participatory Monitoring of Apolobamba National Protected Area for Integrated Management

As almost the whole Apolobamba mountain range falls within the *Área Natural de Manejo Integrado* (ANMIN-A) the Park's administration clearly has a role to play when it comes to the management of glacial lakes. Declared in 1972 as National Reserve Ulla Ulla for the protection of the vicuna (240,000 ha), it was recognized as a UNESCO Biosphere Reserve in 1977 and 13 years later expanded to 483,743 ha and was renamed Apolobamba Natural Area for Integrated Management. Its altitudinal range goes from 800 m a.s.l. in the East to more than 6,000 meters close to the border with Peru.

Bolivian protected areas – "parks with people" – have a tradition of participatory management approaches, so it is little surprising that the monitoring system of ANMIN Apolobamba, an essential tool of overall park management, should also have a participatory character. Monitoring "by the people of the protected area" is the central theme, i.e., park guards and local populations play a crucial role in monitoring water bodies, glaciers, traditional types of potatoes, fauna, peat bogs (*bofedales*), climate, conflicts with wild life, mining, knowledge about traditional plants, tourism, project management, education and financial management.

Due to the already existing working links between various individuals and institutions active in the area, as well as the fact that most park guards originally came from local communities, it was possible to integrate the aspects of glacial lakes into the monitoring framework of Apolobamba National Protected Area for Integrated Management, thus establishing Bolivia's first glacial lake monitoring process, using a participatory approach and involving local communities.



Graphic 5: The institutional set-up for the participatory glacial lake monitoring in ANMIN-Apolobamba

Future perspectives

The perspectives of this collaborative effort between academia, state, civil society and local populations include, among others, the following aspects:

- Long term glacier and glacier lake monitoring as integral part of park management (SERNAP & local people) on the basis of the thesis work and glacier lake inventory prepared by D. Weggenmann of Heidelberg University
- Definition and implementation of adaptation measures by local people, municipalities, park administration, and NGOs on the basis of the thesis on GLOFs and risk management
- Continuing documentation and establishment of a Bolivian glacier archive (BMI)
- Accompanying scientific work by:

  R. Tarquino, Instituto de Ecología, on the consequences of glacier retreat for park management in Apolobamba; and

  C.K. López, FLACSO Ecuador, on water management by local indigenous communities in the area.

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A complete article on the topic "Climate change induced glacier retreat and risk management of Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia" has been submitted for presentation at the Worldwide online Climate Conference CLIMATE 2011 "Climate Change and Disaster Risk Management" to be held November 7 – 12, 2011 (www.climate2011.net).

References and further reading

Apaza Ticona, M. 2009. Reporte preliminar del desastre natural en la comunidad de Keara, 6 noviembre 2009. La Paz: field report (unpublished).

Bradley, R., Vuille, M., Diaz, H. & Vergara, W. 2006. Threats to water supplies in the tropical andes. *Science,* 312**,** 1755-1756.

Canqui, F. 2008. Segundo informe de los talleres de percepciones del cambio climático, comunidades Canuhuma y Ayllu Puyo Puyo. La Paz: technical report (unpublished).

FAO 2009. *Disaster Risk Management in Mountains.*

Hoffmann, D. 2008. Consecuencias del retroceso glaciar en la Cordillera boliviana. *Pirineos,* 16**,** 77-84.

Hoffmann, D. 2010a. Andean glaciers vanish, add socio-economic strains. *Focal Point. Canada's Spotlight on the Americas,* 9**,** 13-15.

Hoffmann, D. 2010b. Cambio Climático y manejo de riesgos en alta montana: Inventario de las lagunas glaciares de la Cordillera Real de Bolivia. *In:* Beck, S. G., Paniagua, N., López, R. P. & Nagashiro, N. (eds.) *Biodiversidad y Ecología en Bolivia - Simposio de los 30 anos del Instituto de Ecología.* La Paz: Instituto de Ecología - Universidad Mayor San Andrés.

Hoffmann D. & Weggenmann, D. 2011. Climate change induced glacier retreat and risk management of Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia. *Paper presented for the Worldwide online Climate Conference CLIMATE 2011* "Climate Change and Disaster Risk Management", *to be held 7 - 12 November 2011.*

Huggel, C. 2004. *Assessment of glacial hazards based on remote sensing and GIS modeling,* Zürich, Univ. Geographisches Institut.

IPCC 2007. *Climate change 2007 the physical science basis; contribution of working group I to the fourth assessment report of the IPCC; technical summary Intergovernmental Panel on Climate Change,* Cambridge [u.a.], Cambridge University Press.

Jordan, E. 1991. *Die Gletscher der bolivianischen Anden eine photogrammetrisch-kartographische Bestandsaufnahme der Gletscher Boliviens als Grundlage für klimatische Deutungen und Potential für die wirtschaftliche Nutzung; mit 34 Tabellen von Ekkehard Jordan,* Stuttgart, Steiner.

OXFAM 2009. Bolivia - Climate change, poverty and adaptation. La Paz.

Ramirez, E. 2007. Impacto del Cambio Climático sobre la Disponibilidad de Recursos Hídricos. *In*: Instituto Boliviano de la Montaña (ed.): *Retroceso de los Glaciares y Recursos Hídricos en Bolivia - De la Investigación a la Acción.* La Paz.

SERNAP 2006a. Apolobamba. Plan de Manejo. *technical paper (unpublished).*

Soruco, A., Vincent, C., Francou, B. & Gonzalez, J. F. 2009. Glacier decline between 1963 and 2006 in the Cordillera Real, Bolivia. *Geophysical Research Letters,* 36.

Tarquino, R. & Flores, P. 2011. Programa de Monitoreo Integral del Área Natural de Manejo Integrado Nacional Apolobamba. *Propuesta de Trabajo, technical document prepared for WCS and SERNAP (unpublished).*

Vuille, M., Francou, B., Wagnon, P., Juen, I., Kaser, G., Mark, B. G. & Bradley, R. S. 2008. Climate change and tropical Andean glaciers: Past, present and future. *Earth-Science Reviews,* 89**,** 79-96.

Weggenmann, D. 2011. *Gletscherseeausbrüche in der Cordillera Apolobamba (Bolivien) - Analyse und Bewertung des Risikopotentials im Rahmen des Klimawandels.* Diploma (unpublished), Heidelberg University.

WGMS 2008. *Global glacier changes: facts and figures,* Zürich, World Glacier Monitoring Service.

The Utility of Laser Scanning for Monitoring Debris-Covered Glaciers and Assessing GLOF Hazard in the Khumbu Himalaya, Nepal

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Introduction

Debris-cover is a common feature in the ablation areas of large valley glaciers in mountain areas around the world, and its presence has important implications for a glacier's response to changing climatic conditions and for its potential for generating environmental hazards such as glacier lake outburst floods (GLOFs). Debris-cover of even modest thickness insulates the ice surface, slowing rates of ablation and permitting the maintenance of glaciers at lower elevations than local temperatures and precipitation rates would otherwise support (Östrem 1959; Nakawo et al. 1999; Shroder et al. 2000). Debris-cover also preserves large areas of stagnant, or "dead" ice at the lowest reaches of large glaciers, where lakes may form during periods of extended negative mass-balance, meaning that the moraines damming such lakes are often ice-cored and thus subject to morphological change as the ice slowly melts. This, in turn, suggests that the stability of such lakes and their potential for catastrophic release is partly a function of the rate at which the debris-covered glaciers are ablating. Measuring the mass-balance of debris-covered glaciers is, however, more difficult than that of "clean-ice"-type glaciers and, despite the clear need to monitor rates of change on such features, efforts to do so remain relatively limited. This brief paper describes the presence of debris-covered glaciers in the Khumbu Himalaya region traversed by *2011 Andean-Himalayan Glacial Lake Exchange and Collaboration Expedition*, the challenges of monitoring change on debris-covered glaciers and potential tools for doing so, and outlines the potential utility of laser scanning technologies in particular for assessing GLOF risk in the region.

Debris-Covered Glaciers in the Khumbu Himalaya

Most large valley glaciers in the Khumbu Himalaya feature significant debris-cover in their ablation areas, and approximately one-third to one-half of the glacier surface area in the region can be so classified (Nakawo et al. 1999; Bolch et al. 2007). Debris-covered glaciers are particularly common here, as throughout the Himalaya, because local topographies and tectonics combine to create high sediment availability but low sediment transfer capacity (Shroder et al. 2000). Most glaciers here are subject to large volumes of ice avalanche and rock fall debris from steep surrounding cliffs, while the wide, low-gradient valleys that characterize the termini of the region's largest glaciers prohibit the rapid removal of the sediment load. Because of thick debris-cover (often as much as 4 meters thick), glacial ice is often preserved. Indeed, the lower reaches of many debris-covered glaciers in the Khumbu Himalaya are composed of inactive dead ice that may or may not have a direct connection to the active, flowing portion of the glacier (Higuchi et al. 1980; Nakawo et al. 1999; Bolch et al. 2007; Bolch et al. 2011) and the large moraines bounding glacier tongues are themselves often ice-cored. Debris thickness can be highly variable, and thus the rates of ablation here can likewise be highly variable (Nakawo et al. 1999). Though the ablation rate under debris cover can be as little as one-tenth that of bare ice (Nakawo et al. 1999), this variability in thickness, the frequent generation of supra-glacial melt ponds and the exposure of bare ice cliffs throughout debris-covered ablation areas make these highly dynamic environments.

Because GLOFs are one of the primary risks to life and property in the Himalaya (Bajracharya et al. 2008), the role of debris-covered glaciers and ice-cored moraines in their generation is an important glaciological focus in the region. GLOF events are generally triggered through one of two mechanisms:

the collapse of rock and/or ice into a glacial lake, with subsequent wave generation leading to a breach of a frontal or lateral moraine dam, or the failure of the moraine dam as a result of structural instability and/or ablation of dead ice at its core (Yamada and Sharma 1993; Watanabe et al. 1995). In either case, a critical component in potential GLOF generation is the geometry, composition, and stability of the moraine dam and, as such, monitoring of these parameters and their change through time is an essential component of GLOF hazard assessment (Sakai et al. 2007; Bolch et al. 2011). This monitoring need is becoming increasingly acute as the number (and size) of glacial lakes at the terminus of Himalayan debris-covered glaciers has grown over the past half-century, thus increasing the GLOF risk throughout the region (Yamada and Sharma 1993; Sakai et al. 2003). These concerns are well-illustrated at Imja Lake, destination of the 2011 research expedition. Having formed from a collection of small supra-glacial ponds present in the 1950s, the lake has expanded to over 2 km in length and ~36 million m^3 (Watanabe et al. 2009). Because of this rapid growth and questions about the stability of the lake's moraine dam, Imja Lake has been identified as a potentially significant GLOF risk. Confounding scientists' ability to quantify the risk has been a lack of knowledge about the exact composition of the moraine dam as well as the rate at which dead ice within the dam is melting. As a result, researchers examining this hazard have repeatedly called for careful monitoring of this moraine as a key component of any hazard analysis (e.g. Sakai et al. 2007; Watanabe et al. 2009). This opinion was reinforced by expedition participants.

Monitoring Change on Debris-Covered Glaciers

Measuring mass-balance and rates of surface change on debris-covered glaciers is often very difficult, in part because identifying the boundary of debris-covered glaciers, either via remote-sensing techniques or even directly in the field, is often a considerable challenge. While some advances in the use of thermal signatures and/or land surface morphology in the mapping of debris-covered ice have recently been made (Paul et al. 2004; Bolch et al. 2007), the more common use of aerial and spaceborne imagery is challenged by the fact that debris-cover on glaciers shares the same spectral signature as the surrounding non-glacial rock (Abermann et al. 2010). In addition, the use of terminus position variability, a common proxy for mass-balance measurements of clean-ice glaciers, is generally inappropriate because the terminus positions of debris-covered glaciers often do not appear to laterally fluctuate but rather down-waste in response to negative mass-balance (Kadota et al. 2000). Furthermore, because access to debris-covered glaciers is frequently limited by the presence of large, unstable boulders, steep terrain, variable debris-cover and melt ponds, the direct measurement of mass-balance change on debris-covered glaciers is often difficult to impossible (Nakawo et al. 1999).

Time-series analysis of digital terrain models (DTMs) has proven to be the most effective means to monitor mass-balance and rates of land-surface change on and around debris-covered glaciers (Bolch et al. 2011). DTMs are models of a surface whereby grid-cells representing individual unit areas are assigned unique elevation values. The relationship between adjacent grid-cells describes surface characteristics such as slope and aspect; the smaller the area represented by each cell, the higher the resolution of the model and thus the more detailed the representation of the surface of interest. Where two different DTMs geo-referenced to the same location exist, the difference in elevations between grid-cells in one DTM to the other can be used to quantify the amount and rate of surface change through time. For example, a grid-cell representing one $10m^2$ section of glacier tongue may have been assigned an elevation of 5,010 m in a DTM created from 1995 data, and an elevation of 4,995 in a DTM created from 2005 data. Depending upon the accuracy of the source data used to create each DTM, a surface deflation of 15 m, or 1.5 m $yr,^{-1}$ can be calculated for that cell. The sum of change for all grid-cells covering the glacier surface thus provides the mass-balance over the period of analysis. Because the accuracy of the elevation measurement has to be greater than the expected thickness change, higher- resolution DTMs produce better results (Pieczonka et al. 2011).

DTMs are generally created in one of three ways: topographic field surveys, photogrammetric analysis or laser scanning. Topographic field surveys employ differential GPS and digital theodolites to produce DTMs, and thus require survey teams to access as many points on the glacier surface as possible. The advantage of this approach is that it provides ground-truthed information at a relatively low cost; however because access to the glacier surface is required, data points are limited to those that are physically accessible, thus excluding steep terrain, exposed ice faces, and melt ponds. Furthermore, this technique is relatively time-intensive (each unique survey point must be individually occupied) and thus a significant level of interpolation is required, resulting in greater uncertainty about the accuracy of the model. This approach has been used to create a DTM at Imja Lake (Sakai et al. 2007), with the goal of providing baseline data for future change analysis and has been used in concert with photogrammetric analysis for investigation of long-term change on the Khumbu Glacier (Nuimura et al. 2011).

Photogrammetric analysis involves the creation of DTMs from stereoscopic aerial or satellite imagery, and is presently the most common means of DTM generation. Indeed, this technique has been used in several recent analyses of Khumbu Himalaya glacier change (Bolch et al. 2011; Lamsal et al. 2011; Nuimura et al. 2011; Pieczonka et al. 2011). Photogrammetric analysis has the distinct advantage of providing time-series extending back several decades, depending on the availability of suitable data. The recent declassification of high-resolution, stereoscopic imagery produced by the US reconnaissance Corona satellite has provided a high-quality baseline for Himalayan studies dating from the early 1960s. Photogrammetric analysis requires high-quality ground control points for image rectification, which thus requires either a GPS-based field campaign or access to some sort of high-quality cartographic reference source, which may limit the potential utility of this technique in some areas. Furthermore, the DTM uncertainty (~1-5 m) is greater than the rate of change for many debris-covered glaciers over shorter time periods, potentially limiting this technique to long-term change analysis rather than the type of high temporal resolution monitoring needed to understand evolving GLOF risks.

The use of laser scanning technology in glaciological studies has thus far been generally limited to airborne LiDAR (Light Detection and Ranging) applications. LiDAR provides high-resolution, high-accuracy DTMs over relatively large study areas; however, flight costs are usually very high and permission to fly may be restricted in sensitive border regions (such as those in the Himalaya). Terrestrial laser scanning (TLS) is a logistically simpler means of employing this same technology. While TLS has thus far been employed in only a handful of alpine glaciological studies, it shows great promise for the type of high spatial and temporal resolution analyses needed for effective monitoring of debris-covered glaciers and their associated GLOF risks.

Laser scanning works by measuring the time needed for a laser pulse to leave the scanner, reach a reflective surface, and be returned to the scanner again. Because the pulse travels at a known velocity, the time is easily converted into a distance measurement. The laser scanner is able to make thousands of such calculations each second, thus generating a "point cloud" that incorporates distance and angle measurements to generate a high resolution (often less than 5 cm) DTM covering an area of several km^2 (Avian and Bauer 2005; Buckley et al. 2008; Kerr et al. 2009). Depending upon the model of laser scanner used, objects up to 6 km away from the scanner can be mapped (Kerr et al. 2009), though resolution is a function of distance and a maximum range of ~1km is preferable (Buckley et al. 2008). This technology has several key advantages. First, because mapping is done remotely, TLS provides data from steep, unstable, crevassed or otherwise inaccessible areas where traditional topographic ground surveys are impossible. Second, TLS field surveys are extremely rapid, with areas covering entire glacier tongues easily mapped in as little as a day (Avian and Bauer 2005). Not only does this decrease the amount of time needed to accomplish a research project (or increase the area that can be covered by the project), it makes TLS especially useful in dynamic situations where rapid response surveying may be necessary (Kerr et al. 2009). Third, TLS surveys provide high spatial resolution of better vertical accuracy than either GPS or photogrammetric surveys and does so at costs much lower than that of airborne LiDAR surveys (Kerr et al. 2009).

TLS is not without its own limitations. Because the technique is ground-based, the amount of coverage is much lower than that of LiDAR or photogrammetric analysis. In glaciological applications, TLS has thus far been limited to studies of change only at the glacier tongue (Avian and Bauer 2005), glaciers of very limited areal extent (Kerr et al. 2009), or individual supra-glacial lakes (Conforti et al. 2005). Studies requiring detailed DTM generation over larger areas (such as the run-out zones of potential GLOF events) will still need to rely upon airborne LiDAR. In addition, the measurement accuracy of TLS (and LiDAR) is impacted by weather conditions, especially humidity and airborne dust, meaning that field campaigns may be interrupted by unfavorable atmospheric circumstances (Avian and Bauer 2005). Finally, TLS equipment is expensive, though improving technology is reducing the cost of equipment. Furthermore, access to pooled equipment and expertise through organizations such as the University Navstar Consortium (UNAVCO, based in the United States) can make TLS research feasible to a broader segment of the research community.

Laser Scanning for GLOF Hazard Assessment in the Khumbu Himalaya

In the Khumbu Himalaya, GLOF hazard assessment is one of the foremost demands facing the scientific community. GLOF hazard assessment is a multi-step process, requiring understanding of the glacial lake itself, the terrain surrounding the lake (especially the moraine dam impounding the lake), the potential downstream routing of water and other debris released during a GLOF event, and the vulnerability of downstream inhabitants in terms of both the location of infrastructure as well as the capacity of individuals and communities to respond to a flood disaster. Laser scanning technology could play an integral role in several of these steps. Prediction of potential GLOF routing requires high-resolution DTMs in order to support effective hydrologic modeling. Because of the amount of area potentially impacted by such an event, airborne LiDAR would provide the most effective tool to generate such a DTM. Earlier efforts to model the impact of an Imja Lake GLOF based on a 30-m DTM have provided useful first-order information, but leave a great deal of uncertainty as to the impact upon specific pieces of infrastructure and property. The 1 to 5-m resolution DTM generated by a time-time LiDAR flight would greatly reduce the uncertainty of impacts from GLOFs of various magnitudes and greatly aid local residents in accessing their own vulnerability. As for monitoring of glacial lake impoundments, TLS can provide the high spatial and temporal resolution necessary to track changing morphology and, potentially, identify the approach of a flood-generating threshold point. The high spatial resolution of TLS allows shorter time periods between scans while still being able to detect surface change. TLS scans of the area between Imja Lake and the front of the lake's impounding moraine could be completed as frequently as semi-annually, which, given the apparent acceleration of ablation in this area, may improve researchers' ability to forecast evolving risk at the lake. For ongoing TLS analysis in the region to be effective, however, the development of local research capacity – in terms of both equipment and expertise – would be essential.

References

Abermann, J., A. Fischer, A. Lambrecht, and T. Geist. 2010. On the potential of very high-resolution repeat DEMs in glacial and periglacial environments. *The Cryosphere* 4 (1):53-65.

Avian, M., and A. Bauer. 2005. First results on monitoring glacier dynamics with the aid of terrestrial laser scanning on Pasterze glacier (Hohe Tauern, Austria).

Bajracharya, S., P. K. Mool, and B. J. Shrestha, eds. 2008. *Global Climate Change and Melting of Himalayan Glaciers*. Edited by P. S. Ranade, *Melting Glaciers and Rising sea levels: Impacts and implications*. Hyderabad, India: The Icfai's University Press.

Bolch, T., M. F. Buchroithner, A. Kunert, and U. Kamp. 2007. Automated delineation of debris-covered glaciers based on ASTER data.

Bolch, T., T. Pieczonka, and D. I. Benn. 2011. Multi-decadal mass loss of glaciers in the Everest area (Nepal Himalaya) derived from stereo imagery. *The Cryosphere* 5:349-358.

Buckley, S. J., J. A. Howell, H. D. Enge, and T. H. Kurz. 2008. Terrestrial laser scanning in geology: data acquisition, processing and accuracy considerations. *Journal of the Geological Society* 165 (3):625.

Conforti, D., P. Deline, G. Mortara, and A. Tamburini. 2005. Terrestrial Scanning Lidar Technology applied to study the evolution of the ice-contact image lake (Mont Blanc, Italy). Paper read at 9th Alpine Glaciological Meeting, at Milan, Italy.

Higuchi, K., H. Fushimi, T. Ohata, S. Takenaka, S. Iwata, K. Yokoyama, H. Higuchi, A. Nagoshi, and T. Iozawa, eds. 1980. *Glacier inventory in the Dudh Kosi region, East Nepal*, *World Glacier Inventory, IAHS-AISH Publ. no. 126*.

Huggel, C., A. Kääb, W. Haeberli, and B. Krummenacher. 2003. Regional-scale GIS-models for assessment of hazards from glacier lake outbursts: evaluation and application in the Swiss Alps.

Kadota, T., K. Seko, T. Aoki, S. Iwata, and S. Yamaguchi, eds. 2000. *Shrinkage of the Khumbu Glacier, east Nepal from 1978 to 1995*. Vol. IAHS Publication No. 264, *Debris-Covered Glaciers*.

Kerr, T., I. Owens, W. Rack, and R. Gardner. 2009. Using ground-based laser scanning to monitor surface change on the Rolleston Glacier, New Zealand. *Journal of Hydrology (New Zealand)* 48 (2):59.

Lamsal, D., T. Sawagaki, and T. Watanabe. 2011. Digital terrain modeling using Corona and ALOS PRISM data to investigate the distal part of Imja Glacier, Khumbu Himal, Nepal. *Journal of Mountain Science* 8 (3):390-402.

Nakawo, M., H. Yabuki, and A. Sakai. 1999. Characteristics of Khumbu Glacier, Nepal Himalaya: recent change in the debris-covered area. *Annals of Glaciology* 28 (1):118-122.

Nuimura, T., K. Fujita, K. Fukui, K. Asahi, R. Aryal, and Y. Ageta. 2011. Temporal Changes in Elevation of the Debris-Covered Ablation Area of Khumbu Glacier in the Nepal Himalaya since 1978. *Arctic, Antarctic, and Alpine Research* 43 (2):246-255.

Östrem, G. 1959. Ice melting under a thin layer of moraine, and the existence of ice cores in moraine ridges. *Geografiska Annaler* 41 (4):228-230.

Paul, F., C. Huggel, and A. Kääb. 2004. Combining satellite multispectral image data and a digital elevation model for mapping debris-covered glaciers. *Remote Sensing of Environment* 89 (4):510-518.

Pieczonka, T., T. Bolch, and M. Buchroithner. 2011. Generation and evaluation of multitemporal digital terrain models of the Mt. Everest area from different optical sensors. *ISPRS Journal of Photogrammetry and Remote Sensing* In Press.

Sakai, A., M. Saito, K. Nishimura, T. Yamada, Y. Iizuka, K. Harada, K. F. Shun'ichi Kobayashi, and C. B. Gurung. 2007. Topographical survey of end moraine and dead ice area at Imja Glacial Lake in 2001 and 2002. *Bulletin of Glaciological Research* 24:29-36.

Sakai, A., T. Yamada, and K. Fujita. 2003. Volume change of Imja glacial lake in the Nepal Himalayas. Paper read at International Symposium on Disaster Mitigation and Basin Wide Water Management, 7-10 December, 2003, at Niigata, Japan.

Shroder, J. F., M. P. Bishop, L. Copland, and V. F. Sloan. 2000. Debris-Covered Glaciers and Rock Glaciers in the Nanga Parbat Himalaya, Pakistan. *Geografiska Annaler. Series A, Physical Geography* 82 (1):17-31.

Watanabe, T., S. Kameyama, and T. Sato. 1995. Imja Glacier dead-ice melt rates and changes in a supra-glacial lake, 1989-1994, Khumbu Himal, Nepal: Danger of lake drainage. *Mountain Research and Development*:293-300.

Watanabe, T., D. Lamsal, and J. D. Ives. 2009. Evaluating the growth characteristics of a glacial lake and its degree of danger of outburst flooding: Imja Glacier, Khumbu Himal, Nepal. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography* 63 (4):255-267.

Yamada, T., and C. K. Sharma, eds. 1993. *Glacier lakes and outburst floods in the Nepal Himalaya*, *Snow and Glacier Hydrology, IAHS Publication No. 218*.

Glaciers, Glacial Lakes and their Management in the Bhutan Himalayas

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Bhutan lies in the eastern Himalayas and is defined by rugged mountainous terrain with elevations ranging from 200 m above mean sea level to over 7,000 m above mean sea level within a distance of less than 175 m. Of the total land area, 20.5% lies above 4 200 m above mean sea level.

Altogether there are 2,674 glacial lakes in Bhutan; 562 lakes of them are associated with glaciers. In general, in terms of geomorphological characteristics, glacial lakes can be grouped into three types: glacial erosion lake, glacial cirque lake, and moraine dammed lakes. The former two types of glacial lakes occupy the lowlands of emptying cirques eroded by ancient glaciers. These glacial lakes are more or less located away from present day glaciers and the downstream banks are usually made of bedrock or covered with thinner layer loose sediment. Both of these glacial lakes do not generally pose an outburst danger. On the other hand, the moraine dammed glacial lakes have the potential for bursting; a standard index to define a lake that is a source of potential danger because of possible bursting does not exist.

The criteria for identifying potentially dangerous glacial lakes are based on field observations, processes and records of past events, geomorphological and geotechnical characteristics of the lake and surroundings, and other physical conditions. The potentially dangerous lakes were identified based on the conditions of lakes, dams, associated mother glaciers, and topographic features around the lakes and glaciers.

From the inventory (ICIMOD, 2001), 24 glacial lakes have been identified as potentially dangerous based on the analysis of data using different criteria and the study of topographic maps and satellite images. The study of topographic maps, satellite images, and field information reveals that most of the identified potentially dangerous lakes started to form more than 40 years ago.

From the 24 potentially dangerous glacial lakes five lie in the Mo chu sub basin, eight in the Pho chu sub basin, seven in the mangdue chu sub basin, three in the Chhamkhar chu sub basin, and one in the Kuri Chu sub basin. The Amo Chu, Ha Chu, Dang Chu, and Nyere Ama Chu basins do not contain potentially dangerous lakes.

In the Bhutan Himalayas glaciers are retreating fast at a rate of 30 to 35m for large glaciers associated with lakes (Ageta et al, 2001). The shrinkage area of glaciers is 10.7% and the rate of enlargement (surface area) of lakes is 3.28%.

GLOF events in the Bhutan Himalayas have not been documented properly. The only GLOF event which has been documented in detail was the devastating GLOF event of 1994 when Luggye Tsho, a lake in the Lunana region, burst, killing 20 people and numerous yaks, and damaging dozens of houses, watermills, and pasture lands.The following table lists the known GLOF events in Bhutan.

In 1998, a Japan-Bhutan joint research team carried out an assessment of GLOFs in Bhutan. In 1999, an Austria-Bhutan expedition carried out an integrated geophysical, hydrological, and geological investigation in the Lunana region with special emphasis on Raptshereng and Thorthomi. Based on the detailed assessment of hazard potential of Raptshereng and Thorthomi glaciers and its lakes, it was found that there is a probability of a worst-case scenario of a GLOF event, possibly originating in the Thorthomi area, unless urgent mitigation measures are taken. Subsequently, the Government of Bhutan initiated a project to lower the water levels of two glacial lakes in Lunana to reduce the likelihood of a GLOF. In

1996, the Raptshereng lake was artificially drained to reduce the hydrostatic pressure on the weakened barrier, the work took two years to reduce the lake water level by 4m. In 2006, the Bhutan National Adaptation Programme of Action (NAPA) issued by the National Environment Commission prioritized the artificial lowering of Thorthomi Lake in its disaster management strategy. The present Thorthomi Lake Artificial Drainage project is currently being implemented under a UNDP-GEF Project with funding from LDCF and co-financing from the Government of Austria, UNDP, WWF, Bhutan, and RGOB. The project aims to reduce the water level of Thorthomi lake by 5m within three years by excavating an artificial channel-widening of the existing outlet channel. The project started from 2008 and will continue until 2012.

Year	Cause	Impact
Before 1950	Not known	There is no information, but a large number of missing end moraines in many of the glaciers in the high Himalayas of Bhutan indicate that GLOF events had taken place in the past.
1957	Bursting of Tarina lake	This GLOF event affected the Punakha-Wangdue valley, which destroyed part of Punakha Dzong. Gansser (1970) attributed this flood to the outburst from Tarina Tsho in Lunana.
1960	Bursting of some lakes in eastern Lunana	The flood destroyed part of Punakha Dzong. The flood is said to have lasted for five days.
1994	Partial burst of Luggye tsho	The only GLOF event properly documented is the one that occurred on October 7, 1994. From a survey conducted on October 20-23, 1994, it was found that 17 lives were lost, 91 households were affected, 12 houses damaged, five water mills washed away, 816 acres of dry land and 965 acres of pasture land were either washed away or covered with sand and silt, 16 yaks were carried away, 36 cowsheds and a full year's manure washed away, six tonnes of food grains lost, 2,838 pieces of wooden shingles and 68 wooden beams washed away, four bridges washed away, two chortens destroyed and the temple at Tsojug was badly damaged.

Early warning systems and flood hazard mapping was done in the valleys of potentially dangerous glacial lakes. GLOF awareness programs are carried out at the community level, involving local people.

Slowing down climate change is only part of the battle; helping nature adapt to change already underway is the important part.

Global Overview of Glaciers and Contemporary Change

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At the Byrd Polar Research Centre we study the cryosphere – which is broader than just the poles. It encompasses areas of ice and snow in Asia, the Americas, Europe, and Africa. It also covers glaciers in tropical regions. Today I am going to give you a general understanding of glaciers, their global change in recent times, and leave you with a few thoughts.

I survived three weeks of the expedition leading up to this workshop, and I want to acknowledge Alton Byers. His love of the region is inspirational and his long-term relational ties with the region are something I strive to emulate in my own work. I would also like to acknowledge John Furlow, USAID; Daene McKinney, University of Texas at Austin; and ICIMOD.

In this overview of global glacier change, I want to begin with some basic properties of glaciers to reflect on important implications of their changes, as we'll continue discussing in this session. Fundamentally, glaciers are rivers of ice, in existence as snow and ice that doesn't melt in the annual cycle, and accumulates enough that they start to flow downslope. The only force acting on glaciers is gravity. But three primary properties are what I want to emphasize here: (1) they are in existence because of the climate; (2) they are vital water resources; and (3) they shape the landscape (powerful eroders, and lake formers). These three primary characteristics have interesting implications. First, glaciers are temporary features on the Earth's surface, just like all lakes, comprising part of a constantly recycling hydrological cycle. Second, glaciers are dynamic; they are in constant motion, and are constantly changing. Finally, they are vital, both dangerous (and life threatening) and life giving. We live in the wake of glaciers.

When snow falls it transform to ice; if the ice doesn't melt it will flow – and then you have a glacier.

Glaciers are constantly being renewed by accumulation of additional mass in the form of snow, and also ablating, or losing mass by melting and sublimating; as such, glaciers exist in an equilibrium between mass gain and mass loss. If there is more accumulation than ablation, the glacier will grow in extent. Likewise, the glacier will recede if there is more ablation than accumulation. One can even envision an "equilibrium line" as the boundary between accumulation and ablation zones on a glacier. It is our interest as glacial geologists to understand how this equilibrium line changes in time and space because of climate change and other factors. Glaciers are thus climatically sensitive, and can be used as climate change indicators, and even, as I'll show later, archives of past climates (i.e. ice cores). As a result of this accumulation and ablation, material is constantly being eroded and moved down the slope by glaciers, even if the glacier is apparently in equilibrium and not advancing (growing) or retreating (shrinking). They are literally rivers of ice as is well depicted by these time lapse photo-videos of glaciers in Alaska and the Alps.

Glaciers have many forms; they can be high and steep alpine glaciers, as in the case of this Himalayan hanging glacier, or be vast, extensive, and kilometres thick, as in this polar outlet glacier in Antarctica. Glaciers exist at high elevation or at high latitudes.

Glaciers are Earth's largest freshwater reservoir: 97% of our planet's water is saline, and of the remaining 3% freshwater 68.7% is locked up in the form of ice. Of this, 61% is in Antarctica and 5% in Greenland. The remaining ~3% is found in smaller mountain glaciers and ice caps around the world.

Glaciers currently cover 11% of the Earth. If you look at seasonal snow cover, this figure expands to almost 30% of the land surface covered by snow and ice. This shows not only the current extent of Earth's cryosphere, but also the impressive amount of seasonal variation. Seasonal snows are an important water resource in many mid-to high latitude (particularly in the northern hemisphere) locations.

If we look back 20,000 years ago (to the last maximum glacial extent, or Last Glacial Maximum-LGM), glaciers covered 32% of the Earth. However, it is also important to recall that the Earth has not always been covered by glaciers. Ice ages have been few and far between when we consider the full 4.6 billion year history of our planet. We actually still live in what is called the late-Cenozoic Ice Age, covering the last 2-3 million years. It is still technically an ice age because of the existence of continental-sized ice sheets (Antarctica and Greenland).

If you look at where Ohio is, it is obvious we are very far from current glaciers today. Nevertheless, in Ohio, multiple series of glacier advance and retreat have shaped the landscape of our state. The sediments, minerals in the soil, and waters in the aquifers owe their existence to glaciers, and currently allow us to grow our abundant harvests of corn and soy. Furthermore, one way to appreciate the glacial nature of our modern corn yields is to see the overlap of terrain in these maps of both glacial geology and corn production (with ethanol plants).

The focus of this workshop is mountain glaciers. Mountain glaciers around the world cover 330,000 km^2 of a total glacier surface area of 15 million km^2 (including Antarctica and Greenland).

Most of the mountain glaciers are in Northern America and Central Asia, but there are also significant mountain glaciers in Northern Asia and South America, with much less in Central Europe, Africa, and even New Guinea. By and large, mountain glaciers are receding, and have even been a major contributor to sea level rise over the last century. Glacier retreat is a worldwide phenomenon. It will affect many things, including the water supply for millions in northern India and in the Andes mountains. Series of successive photos capture the extent of this recession that has been especially rapid over the last 30-50 years (e.g. photos from Asia, North America, Europe, South America).

Scientists from the Byrd Polar Research Center of the Ohio State University have had a long-term interest in taking ice cores to study past climate changes from glaciers in the low latitudes, in particular in the tropical Andes of Peru, from which we are learning many things. The Quelccaya Ice Cap (QIC) located at 13 degrees south is where we have had the longest series of projects and observations extending over the last 40 years. The first tropical ice core was taken from the QIC in 1983. And starting in the 1970s we have been taking terrestrial photogrammetric images of the largest outlet glacier from the QIC, called the Qori Kalis glacier. This has allowed us to view not only the surface area changes, but also the total volume changes of this glacier. We have also recovered ancient plants being exposed from under the melting ice cap edge. These are actually still rooted in place, and have been carbon-dated as more than 5,000 years old. This shows that this glacier was gone, but then rapidly froze over, an example of how rapid climate changes can occur.

Observations of glaciers began only relatively recently, but it is clear that mass balance is decreasing (which is referred to as negative mass balance). Surface area and thickness (volume) are also both decreasing. As a result of our research in the Peruvian Cordillera Blanca range (the most glacierized tropical mountain range on Earth), we have shown that glaciers are thinning more rapidly than might be predicted by surface are changes. Using airborne LiDAR (high resolution laser scanning of surface topography), we have computed volume losses that are 2 to 5 times greater than what is predicted using an empirical formula based on surface area loss. What does this mean? Many rapidly growing urban areas in the Andes (and other regions) rely on mountain runoff originating in glaciers as water resources. With population growth and urbanization there is an increased demand for water. Glacier melt will also contribute to sea level rise.

But again, the Earth is a dynamic integrated system, and has only had glaciers for a small period of our planet's history; in this sense, the only constant is change. These glaciers and glacier lakes are transient features. If we continue to increase our atmospheric carbon dioxide levels, forcing warming and more glacier melt, we may be going back to the hot-house climate last experienced during the Cretaceous period. This was a very different world, with sea levels much higher. The rate of these profound climatic and resulting glacier environmental changes is of primary concern as we consider the capacity of our societies to adapt.

South-South Knowledge Exchange and Collaboration: Lessons from the Imja Expedition, September 2011

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Water resources and glaciers in Nepal

Nepal covers an area of 147,181 km^2 extending from 8,848 m at Mount Everest (Sagarmatha) in the north to less than 100 m in Terai plains in the South – all within a distance of only 160 to 270 km. The rivers can be classified into three categories: (1) major rivers (including the Koshi, Narayani/Gandaki, Karnali, and Mahakali), which originate in the Himalayas and high mountains, (2) medium rivers (including the Kankai, Kamala, Bagmati, West Rapti, and Babai), which originate in the middle mountains, and (3) small rivers, which originate in the Siwalik range or in the Terai. The major rivers are fed by snow and glaciers in the Himalayas, gain substantial flow as they pass through the valleys, and emerge as large rivers in the Terai.

The major rivers of Nepal have a surplus of water, even in the dry season. They are the ideal for hydropower generation because of the steep topography and narrow valleys through which they flow. The medium and small rivers feed large areas of agricultural land in the southern Terai plains. Glacier melt contributes to dry season flow, so large glaciated areas at the headwaters produce more discharge. The major river basins such as the Koshi, Narayani/Gandaki, Karnali, and Mahakali have a surplus of water for agriculture, even in the dry season, but the medium rivers require water storage through high dams or inter-basin transfers of water. The Bheri-Babai Diversion, Sun-Koshi-Kamala Diversion, and Kali Gandaki-Tinau Diversion are some of the pipeline projects currently in place.

About 74% of the total annual surface flow in Nepal occurs in the four-month monsoon from June to September; in the dry season there is water scarcity in medium basins and the southern rivers have low or no flow. To augment dry season flow, 28 water storage projects have been proposed: 22 multipurpose storage projects in major rivers to store 132 billion cubic meters of water, five storage projects in medium rivers to store 6 billion cubic meters of water, and one storage project in a small river to store 85 million cubic meters of water (the same volume as Tsho Rolpa). These multipurpose projects have hydropower, irrigation, flood control, and other benefits. These proposed storage reservoirs are important to mitigate the impacts of climate change and for adaptation to melting glaciers and the worst-case scenario of a world without glaciers.

The rivers flowing from Nepal have a total catchment area of 1,076,000 km^2, of which 13.68% is in Nepal, 3.48% is in the Tibet Autonomous Region of China (the upper catchment), 4.28% is in Bangladesh, and the largest area of 78.57% is in India. Snow and ice in the catchment area of Nepal contribute significantly to dry season flow. Glaciers and glacial lakes are important contributors to the dry season flow, not only in Nepal but also in India to the Ganges. As a consequence of climate change, glaciers are melting, large glacial lakes are increasing in size, and small glacial lakes are disappearing. The reduction of glacier area from 5,324 square kilometres to 4,242 square kilometres between 2001 and 2009 (ICIMOD 2011) has caused severe water stresses in all of the rivers of Nepal, particularly in medium and small rivers.

Nepal has a total theoretical power generation capacity of 83,290 MW, of which 42,110 MW is economically feasible (NWP 2004). Most of the hydropower sites are at the headwaters of river basins close to glacial lakes and are, therefore, at risk of impact from glacial lake outburst flood (GLOF).

High priority potential dangerous lakes in Nepal

The 1981 Zhangzangbo GLOF event in Tibet (China) caused significant damage to the Sunkoshi Hydropower Project in Nepal. This led to a joint study on glacial lakes in the Pumqu (Arun) and Poiqu (Bhote-Sun Koshi) basins in the Tibet Autonomous Region of China (Lanzhou Institute of Glaciology and Geocryology et al. 1988). The existence of potentially dangerous lakes in the upper catchment area of Tibet calls for the sharing of transboundary information on GLOF events and highlights the need for an early warning system between Nepal and China.

After the 1985 Dig Cho event, which nearly completely destroyed the Namche Hydropower Project, a study of glacial lakes was conducted in the area. The Lower Barun, Tsho Rolpa, and Thulagi – the location of the Arun, Khimti, and Marsyangdi hydropower projects – were selected for study by Water and Energy Commission Secretariat (WECS) and Department of Hydrology and Meteorology (DHM) of Nepal. Remote sensing was used by ICIMOD to prepared an inventory of glaciers and glacial lakes, which identified 20 potentially dangerous lakes in Nepal (Mool et al. 2001). Later, 21 priority glacial lakes – six high priority (Tsho Rolpa, Thulagi, Imja, Lower Barun, Lumding, West Chamlang), four medium priority, and 11 low priority – were identified (ICIMOD 2011). Of the six high priority glacial lakes, Imja, Thulagi, and Tsho Rolpa were selected for field investigation to assess GLOF hazard and vulnerability in the river valleys.

GLOF hazard and vulnerability assessment in Nepal

Imja Lake (27° 54′ N, 86° 56′ E, at 5,010 masl), Thulagi Glacial Lake (28° 29′ N, 84° 29′ E, at 4,044 masl), and Tsho Rolpa Glacial Lake (27° 52' N, 86° 28' E, at 4,546 masl) were assessed for GLOF hazard and vulnerability in the Nepal Himalayas. These lakes developed in the middle of the 20th Century as small supra ponds. They expanded at rates of 0.0266 km^2 (Imja), 0.0115 km^2 (Thulagi), and 0.0129 km^2 (Tsho Rolpa) per year. Ice calving and melting of the glacier terminus in contact with the lake expanded these lakes towards the glacier terminus at rates of 42–47 m, 35–41 m, and 17–20 m per year, for Imja, Thulagi, and Tsho Rolpa, respectively. The storage volume of the lakes increased as a result of the mass wasting of the glaciers and the melting of buried ice at the bottom. The increment rates were 0.50 million cubic meters, 0.53 million cubic meters, and 0.26 million cubic meters per year for Imja, Thulagi, and Tsho Rolpa, respectively.

Tsho Rolpa has the largest storage volume of 86 million cubic meters, highest dam height at 216 m, lowest free board at 5 m, and narrowest dam width at 50 m. This lake has the highest GLOF hazard despite the mitigation work done to lower the lake level by 3 m in 2000. Imja and Thulagi have the same storage volume of about 35 million cubic meters each, but Imja poses a lower potential GLOF hazard than Thulagi because of its lower dam height (31 m) and its thicker moraine dam (567 m).

It is forecast that a 20 m breach would generate a peak discharge of 5,817 cubic meters per second in Imja, 4750 cubic meters per second in Thulagi, and 7,242 cubic meters per second in Tsho Rolpa. These peak floods would carry large debris, eroding the side valleys and scouring the riverbeds. At several sections of the river valley, a series of erosion and sedimentation processes would take place, destroying infrastructure and resulting in loss of life. The estimated potential loss to physical infrastructure from GLOF in the 100 km stretch from the glacial lake is USD 11.89 million for Imja, USD 406.73 million for Thulagi, and USD 1.84 million for Tsho Rolpa. Thulagi has a high GLOF vulnerability because of the probable physical damage to the Middle Marsyangdi Hydroelectric Project (69 MW). The Upper Tamakoshi Hydroelectric Project (456 MW), which is under construction, and other hydropower projects on the Tama Koshi, which are licensed for 1,180 MW, would suffer tremendous loss if there were a GLOF at Tsho Rolpa. At present, the Tsho Rolpa Glacial Lake has the highest GLOF hazard and vulnerability, and the Thulagi has a higher GLOF hazard and vulnerability than Imja. Therefore, in the present context, any mitigation work for GLOF vulnerability risk reduction should focus on Tsho Rolpa, and then Thulagi and Imja.

Observations during the Imja Lake Expedition

The following observations were made of Imja Lake during the expedition in September 2011:

- The vertical glacier snout at Imja, which was observed during an earlier expedition in May 2009, was not present in September 2011. The thick debris cover and low glacier calving rate is likely to reduce the rate of lake expansion towards the glacier terminus, similar to at Tsho Rolpa, which experienced glacier snout recession in the past.

- The Lhotse Shar Glacier has impeded the movement of Imja Glacier and lake expansion will be more towards the Lhotse Shar Glacier than Imja Glacier in coming years.
- The Lhotse Shar Glacier has many supra ponds at high elevations, which may accelerate glacier melting and increase lake outflow during dry months.
- The input of local cross drainage entering from the right bank may accelerate glacier melt and increase englacial drainage.
- The lake shoreline is expected to expand to the northwest of the lake through the collapse of part of the end-moraine complex at a faster rate.
- The melting of the thermokarst exposed at left bank at the end of lake is likely to accelerate. The river channel may widen at this point depending on the extent of buried ice. The end-moraine complex and the lateral moraines are in no way destabilized by this melting.

Lessons learned from the Imja Lake Expedition

The Expedition to Imja Lake as part of the "South-South Knowledge Exchange and Collaboration between Experts and Practitioners from the Hindu Kush-Himalaya, Andes, and Central Asian Mountains under the theme of Improved Adaptation Learning and Resilient Livelihoods" was conducted to find solutions to the increased risk of GLOF hazard in the region as a result of the melting of glaciers with climate change. The expedition greatly enhanced our knowledge on Imja Lake and facilitated the exchange of Peruvian knowledge and expertise in glacier hazard management. Peru has been working in glacier hazard management since 1951, applying mainly structural engineering measures on 34 dangerous glacial lakes. This knowledge and these techniques may have application in the Hindu Kush-Himalayas and Central Asia, provided scientific research and assessments are conducted before any mitigation work is carried out. Some of the important parameters to consider are:

- **Scientific knowledge and the gaps:** We need to conduct research to evaluate the lake and its morphology and to assess the stability of the moraine dam (including its composition, compaction, and the existence of buried ice, taking into account external factors such as hydrology, meteorology, glaciology, and topography). We also need to understand GLOF triggers and processes.
- **Community participation:** This covers the sharing of knowledge and experience with the community and valuing their knowledge and experience. We need to look at ways of disseminating information and of working together in partnership.
- **Coordination of activities:** Coordination has to happen at the central level (with the government, donors, stakeholders) and at the local level (with all stakeholders). There must also be coordination between researchers and local stakeholders.
- **Funding sources:** We need to explore all potential sources of funding for scientific research, mitigation, and adaptation to climate induced hazards including governments, donors, and the private sector.
- **Partnerships:** We need to cultivate functional partnerships between the Hindu Kush-Himalayas, Andes, and Central Asian Mountains for the exchange of knowledge and expertise.
- **Integration of improved adaptation and resilient livelihoods:** We need to integrate improved adaptation and resilient livelihoods into glacier lake hazard management and provide incentives to communities who are providing ecosystem services to the people downstream.

Scientific knowledge and gaps

Imja Lake is one of the most highly accessible glacier lakes in the Hindu-Kush Himalayan region and a lot of research has been conducted on this lake by the Water and Energy Commission Secretariat, Department of Hydrology and Meteorology, and other researchers (see Yamada 1992; Watanabe et al. 1994; Kettelmann and Watanabe 1998; DHM 2001; Sakai et al. 2005; GEN et al. 2006). Some of the key areas for future research include:

- Research on the thickness of buried ice beneath the lake bottom, its melting rate, and the processes involved.
- Research on the thickness of buried ice and any frozen ground in the end-moraine complex and lateral moraines, and the composition of moraine dam materials in order to evaluate the stability of the dam and the risk of overtopping or piping failure caused by seepage.
- The glaciers around the lake are melting and local drainage (e.g., on the right bank) has contributed to the inflow into Imja lake and accelerated melting. Supra ponds are enlarging and contributing englacial drainage. Thus, there is a need to estimate the inflow into the lake and the outflow capacity of the outlet.
- Triggering factors that could generate waves capable of breaching the width of the moraine dam and overtopping the freeboard (such as the collapse of the right lateral moraine) need to be investigated.

Community participation

A GLOF would directly impact on the 445 houses and 1,928 people up to 100 km downstream from Imja Lake within the narrow and steep river valley (ICIMOD 2011). Involving communities and other stakeholders scattered over such a long distance is a challenging task. In most cases, the people living at or near the headwaters play a significant role, and have the most input into mitigation measures. For instance the people in Dingboche are frequently consulted by researchers and organizations working in GLOF hazard management, but the people in the Phakding, Ghat, and other low-lying settlements, which were also affected by the 1985 Dig Cho GLOF and have a high probability of being affected by future GLOF events, are not as concerned or involved. Thus, a formal institution operating at the local level, such as a village development committee (a local government administrative unit in Nepal), needs to be involved so that all of the stakeholders within the probable GLOF impact area are organized at the local level. This is a challenging task.

Interactions with local people from Dingboche at Imja Lake during the expedition enabled experts to exchange knowledge and experience with local people and were successful in communicating knowledge and building trust. The participation of local people in research and mitigation work is crucial to its success. Approximately USD 1 million was spent to establish an early warning system in Tsho Rolpa, but the system is not operational as the local community was not involved in the implementation and maintenance of the system and therefore did not feel ownership of it. There is need to re-establish the early warning system at Tsho Rolpa, and develop one at Thulagi and Imja, that is owned and operated by the local community.

Coordination of activities

In Nepal, the Department of Hydrology and Meteorology is responsible for glaciers and glacial lake activities; the Water and Energy Commission Secretariat is responsible for glacial lakes and policy-related issues; the Department of Water Induced Disaster Prevention is responsible for water-induced disasters and glacial lakes; and the Ministry of Environment is responsible for the environment and climate change-related issues. Because of budget constraints and lack of manpower, these institutions are not carrying out regular and comprehensive research on glaciers and glacial lakes. There is need to coordinate and prioritize research work among these agencies to reduce duplication and to optimize the use of resources and mechanisms for sharing knowledge and information.

Funding sources

There is need for research on glacial lakes and GLOF-related hazards in the Hindu Kush-Himalayas, Andes, and Central Asia to mitigate the impacts of such hazards. The lack of road access to glacial lakes in Nepal makes mitigation work costly compared to in the Andes. Therefore, mitigation must be focused on those lakes with a high GLOF hazard and vulnerability. Power producers such as the Upper Tamakoshi Hydropower Project and other projects on the Tama Koshi have an interest in contributing to mitigation work in the headwaters. The Government policy promoting public-private-partnerships in this field should be implemented and enacted upon.

More funding for scientific research, mitigation, and adaptation is needed from donor agencies such as the World Bank, United Nations Development Program, United Nations Environment Program, United

States Agency for International Development, the Norwegian Government, and the Swedish International Development Cooperation Agency, which are already directly and indirectly involved in reducing climate induced hazards. Regional and international organizations, governments, and the private sector should build a partnership to facilitate adaptation to climate induced hazards.

Partnerships between the Hindu Kush-Himalayas, Andes and Central Asian Mountains

The South-South Knowledge Exchange and Collaboration program has given researchers, officials, and experts from 15 different countries the opportunity to participate in the Imja Glacial Lake Expedition to share their knowledge and experience on climate change induced glacial melting and GLOF hazards. Successes in other countries/regions may be able to be replicated in the Hindu Kush-Himalayas and Central Asian Mountains, particularly in terms of mitigation and adaptation. Ideally the South-South partnership should be continued and expanded into a global glacial lake partnership.

Integration of improved adaptation and resilient livelihoods

There is need to compensate the people living at the headwaters of the major rivers in the Hindu Kush-Himalayas for maintaining these important water resources and the ecological diversity of the region for the benefit of the people downstream. Incentives could be offered for the installation of clean energy technology, such as solar systems and micro-hydro for lighting and cooking, to local communities to encourage them to preserve the forests and biodiversity of the region. The local community at Debuche in the Kumbhu region and other areas should also receive compensation for garbage disposal by trekkers and mountaineers. Other new innovative ideas to improve local adaptation and resilient livelihood need to be explored.

References

DHM (1997) Thulagi glacier lake study. Final report submitted to the Department of Hydrology and Meteorology, His Majesty's Government of Nepal in cooperation with the Federal Institute for Geo-sciences and Natural Resources (BGR), Hannover, Germany

DHM (2001) Topographical/profile survey and establishment of benchmarks of the end moraine of Imja glacier lake. Final report prepared by Dip Consultancy for the Department of Hydrology and Meteorology, Kathmandu, Nepal

GEN; CREH; NU; DHM (2006) Data report 4 (2001–2004), GEN 2001–2002: Imja glacier lake in Khumbu, East Nepal. Report of the Glaciological Expedition to Nepal, Cryosphere Research in the Himalaya, Department of Hydrospheric Atmospheric Science, Graduate School of Environmental Studies, Nagoya University, Department of Hydrology and Meteorology, His Majesty's Government of Nepal

ICIMOD (2011) Glacial lakes and glacial lake outburst floods in Nepal. Kathmandu: ICIMOD

Kettelmann, R., Watanabe, T., 1998. Approaches to Reducing the Hazard of an Outburst Flood of Imja Glacier Lake, Khumbu Himal. In Chalise, S.R., Khanal, N.R. (eds) Proceeding of the International Conference on Ecohydrology of High Mountain Areas, Kathmandu, Nepal, 24-28 March 1996, pp 359–366. Kathmandu: ICIMOD

Lanzhou Institute of Glaciology and Geocryology; WECS; Nepal Electricity Authority (1988) Report on first expedition to glaciers and glacier lakes in the Pumqu (Arun) and Poique (Bhote-Sun Kosi) river basins, Xizang (Tibet), China, Sino-Nepalese investigation of glacier lake outburst floods in the Himalaya. Beijing: Science Press

Mool, PK; Bajracharya, SR; Joshi, SP (2001) Inventory of glaciers, glacial lakes, and glacial lake outburst flood monitoring and early warning systems in the Hindu Kush-Himalayan Region – Nepal. Kathmandu: ICIMOD

Sakai, A; Fujita, K; Yamada, T (2005) 'Expansion of the Imja glacier lake in the East Nepal Himalayas.' In Mavlyudov, BR (ed.) Glacier caves and glacial karst in high mountains and Polar regions (7th GLACKIPR symposium), pp 74–79. Moscow: Institute of Geography of the Russian Academy of Sciences

Watanabe, T; Ives, JD; Hammond, JE (1994) 'Rapid growth of a glacial lake in Khumbu Himal, Himalaya: Prospects for a catastrophic flood'. In Mountain Research and Development 14(4): 329–340

WECS (2002) Water resources strategy 2002 report. Kathmandu: Water and Energy Commission Secretariat, Government of Nepal

WECS (1993) Interim report on the field investigation on the Tsho Rolpa glacier lake, Rolwaling Valley, WECS Report No. 3/4/021193/1/1, Seq. No. 436. Kathmandu: Water and Energy Commission Secretariat, Government of Nepal

WECS (1995) Preliminary report on the Thulagi glacier lake, Dhana Khola, Marsyangdi Basin, WECS Report No. 473, Seq. No. 2/3/170795/1/1. Kathmandu: Water and Energy Commission Secretariat, Government of Nepal

WECS (1996) Report on the investigations of Tsho Rolpa glacier lake, Rolwaling Valley. Kathmandu: Water and Energy Commission Secretariat, Government of Nepal and Japan International Cooperation Agency

WECS (2004) National water plan 2004 report. Kathmandu: Water and Energy Commission Secretariat, Government of Nepal

Yamada, T (1992) Report for the first research expedition to Imja glacier lake – 25 March to 12 April 1992, WECS Report No. 3/4/120892/1/1, Seq. No. 412. Kathmandu: Water and Energy Commission Secretariat, Government of Nepal and Japan International Cooperation Agency

Present Status of Pakistan's Glaciers and Glacier Recession Impacts in Pakistan

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The world's mighty Hindu Kush–Karakoram–Himalaya (HKH) mountain ranges, called the "Roof of the World," stretch across eight countries: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan as shown in Figure 1. These mountains possess the world's third largest snow/ice mass after the Antarctic and Greenland ice sheets. These frozen water reservoirs in the sky are the only sustainable source of fresh water supply and ground water recharge in the HKH region. The meltwater from snow and ice in the HKH region is a major contributor to the river flows of Indus, Ganges, Brahmaputra, and Yarlung Tsangpo. The well-being of more than 1.3 billion people in the regional countries depends on the adequate supply of fresh water from these rivers, regulated to a large extent by the presence of natural reservoirs in the form of glaciers. Table 1 shows the relative contribution of glacier melt in these rivers.

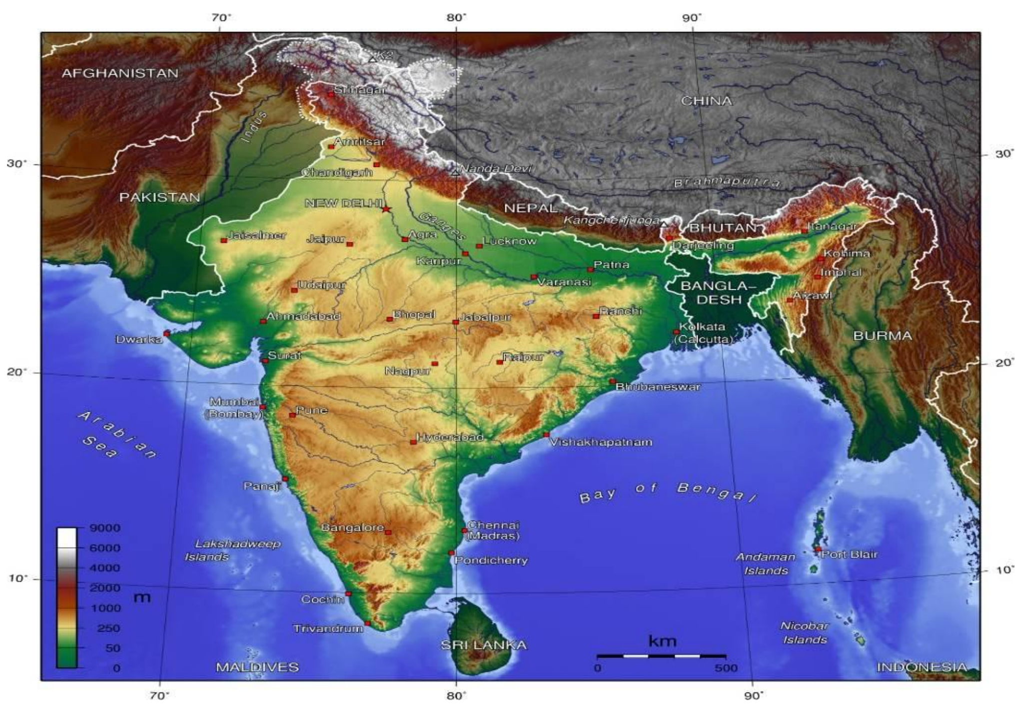

Figure 1: The South Asian Region

Table 1: Principal Rivers of the Himalayan Region (Source: ICIMOD Report)

Principal Rivers of the Himalayan Region			
River Name	Length (km)	Mean Discharge (m^3/s)	Glacier Melt in River Flow (%)
Yangtze	6,300	34,000	18.5
Brahmaputra	2,948	19,824	12.3
Ganges	2,057	18,691	9.1
Irrawaddy	2,170	13,565	Small
Mekong	4,600	11,048	6.6
Indus	2,900	5,533	44.8
Salween	2,800	1,494	8.8
Yellow	5,464	1,365	1.3
Tarim	2,030	146	40.2

Among the HKH Mountain ranges, Karakoram Mountains have the highest snow and ice reserves covering an area of ice between 27 -37 % as compared to Himalayan ranges (17%) and European Alps (22%). The total number of glaciers in the Karakoram is about 5,218, covering an area of about 15,000 sq. km. The number of total glacial lakes identified using satellite images in Pakistan are 2,420. Out of these, 52 are considered as potentially dangerous. (Roohi et al. 2007).

In Pakistan, glaciers of the Karakoram Range contribute up to 80% flow in the Indus River System through its tributaries (see Figure 2) and are reported to be under threat due to changing climate. Any change in glacial behavior will have major consequences on water availability in the Indus River system, thus raising perturbing food and water security concerns and at the same time risking the livelihood of over 43% of the country's population that are directly or indirectly linked with agriculture. Water loss would also reduce the availability of power, which is already a serious development constraint in Pakistan. At present, 34% of total electricity generation in the country is based on hydel sources.

The phenomenon of glacier retreat is of particular concern to Pakistan since its economy is heavily dependent upon agriculture, which in turn depends upon the meltwater from the glaciers and snowmelt in HKH. According to the World Bank Report, 2005, "Pakistan's Water Economy: Running Dry" Western Himalayan glaciers will retreat for next 50 years causing an increase in Indus River flows. Then the glacier reservoirs will be empty, resulting in a terrifying decrease of 30% to 40% in the flow of the Indus Basin over the century. Despite the fact that glaciers are reported receding worldwide, Kenneth Hewitt (2005) reported widespread glacier expansion in the Central Karakoram during late 1990s. These conflicting findings mark the need of research on the impact of climate change on glaciers, essential.

Figure 2: The Glacierised River Basins of Northern Pakistan (Source: Roohi et al. (2005))

Indus is the river which has highest contribution of snow and ice melt (44.8%) as compared to the other principal rivers of the whole Himalayan Region, as shown in Table 1.

In upper Indus Basin of Pakistan, the concentration of snow and ice is highest in the three glacierized basins namely Hunza, Shigar, and Shyok. These basins have more than 80% of ice reserves and also have big glacier peaks in them.

The Karakoram Glaciers showed mixed response to changing climate in the region. Dirk Scherler et al. (2011), on the basis of 42 studied glaciers in Karakoram Region, found that 58% of them are advancing whereas rest of the glaciers are retreating. They concluded that the greater debris cover may be the reason for the advancement. Roohi et al. (2005), during the development of an inventory of glaciers and glacial lakes of Pakistan observed most of the glaciers are retreating. According to IPCC AR4 (2007), glacier melt in Himalayas is projected to increase flooding within next two to three decades. This will be followed by decreased river flows as the glaciers recede. Global Change Impact Studies Centre (GCISC) Pakistan have also done some work based upon remote sensing (RS) and geographic information system (GIS) and found the mixed trend of the glaciers in the Hunza River Catchment.

Conclusively, it is to be said that monitoring of glaciers and glacial lakes of HKH Region of Pakistan, especially of Karakoram, is very necessary.

Way forward:

- Regional collaboration is essentially required to address the water related issues and managing the water resources under changing climate
- Application of State-of-the-art remote sensing & GIS Tools & Techniques to assess present status of Karakoram Glaciers using high resolution satellite data
- Field measurements on selected glaciers for validation of RS/GIS results
- Assess implications of Climate Change related changes in water flow on irrigation system, hydropower generation and influx of sea water in Indus deltaic region

- Develop appropriate Adaptation Measures to counter the negative impacts

References:

1. Scherler, D., Bookhagen, B. and Strecker, M.R. (2011) Spatially Variable Response of Himalayan Glaciers to Climate Change affected by Debris Cover. Nature Geoscience (DOI:10, 1038/NGEO1068)

2. ICIMOD, WRRI/PARC, (2005) Inventory of Glaciers and Glacial Lakes and the Identification of Potential Glacial Lake Outburst Floods (GLOFs) Affected by Global Warming in the Mountains of Himalayan Region.

3. Roohi, R. (2007), Research on Global Changes in Pakistan. In R. Baudo, G. Tartari, and E. Vuillermoz (Ed.), Mountains Witnesses of Global Changes. (pp.329-340). Elsevier.

4. Roohi, R., Ashraf, A., and Naz, R. (2007) Glaciers – The Barometer of Climate Change, World Environment Day June, 2007

5. Hewitt, K. (2005) The Karakoram Anomaly? Glacier Expansion and the 'Elevation Effect,' Karakoram Himalaya. Mountain Research and Development 25(4):332-340.2005 doi: 10.1659/0276-4741(2005)025[0332:TKAGEA]2.0.CO;2

Glacial Lakes and Associated Floods in the Hindu Kush-Himalayas

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It is now generally accepted that climate warming is having a significant impact on the Himalayas. One of its effects is that glaciers are thinning and retreating throughout much of the region. This is accompanied by formation of meltwater lakes, both on the glacier surface and in front of them. Already several, such as Imja Lake and Tsho Rolpa, are more than two kilometres long and about 100 meters deep. Glacial lakes are usually dammed by end moraines; these are mounds of rubble carried down the valley by glaciers and deposited as ridges when the glaciers were much larger than today. Because the moraines are not well consolidated and frequently contain an ice core that is also melting, they are often unstable. This means that glacial lakes are in danger of bursting their moraine dams to cause a catastrophic flood (GLOF) in the valley below. Several outbursts have already occurred with attendant loss of life and property, although it should be noted that the actual threat is often exaggerated.

Following identification of lakes that pose a threat, measures can be taken to reduce the danger and install early warning systems. Glacial lakes can also be beneficial, both as new sources of water and hydro-electricity. Their identification and management requires good cooperation with the local people.

Glacial lakes and glacial lake outburst floods

With the onset of climate warming about 1850-1905 (generally considered as the end of the Little Ice Age), many glaciers throughout the world, including in the HKH region, began to thin and their termini to retreat. This has led to the creation of many glacial lakes. The lakes of interest at present are those that form on the surface of the terminus moraine.

The amount of destruction caused by a GLOF will depend on many factors, especially the original volume of water in the lake and the rapidity and completeness of the drainage. The latter will be influenced by the level of instability of the moraine dam and, therefore, its rate of collapse. Some lakes may drain quite slowly and so prove comparatively harmless; others may empty within a very short time (hours) and be catastrophic.

The actual failure of the moraine dam may be influenced by many factors (triggers). Ice or snow avalanches, or rockfalls (landslides) may cascade into the lake from adjacent precipitous mountain walls to cause a surge wave in the lake that overtops the dam. Seepage of water though the dam, especially where the ice core is melting, may undermine the unconsolidated materials and cause a total or partial collapse – the resulting discharge of large volumes of water will then accelerate failure of the dam. The lake level may rise due to the inflow of an increasing amount of meltwater until it overflows the dam at its lowest point and thereafter erodes a channel through it. Several of these processes may act together.

Catastrophic glacial lake outbursts have occurred in many mountain ranges throughout the world and, in some instances, have caused extensive damage and loss of life. Glacial lakes are potentially unstable because their end moraines are composed of unsorted and unconsolidated boulders, gravels, sands, and clays. Furthermore, they are frequently reinforced by frozen cores (permafrost) that, like the glaciers themselves, are now beginning to melt. As the volume of a lake that is accumulating behind an end moraine increases, hydrostatic pressure builds up to put additional stress on the moraine dam causing it to become more unstable. Eventually, it may fail and release much, or all, of the lake water. Depending on the manner in which the dam fails, the ensuing outbreak of water can be sudden and highly dangerous to people and infrastructure located downstream. The surging flood water will often have the energy to entrain large masses of loose material (boulders, gravel, sand, and clay, as well as any broken masonry or torn out trees) as it is propelled down-valley. The resulting cataract is known as a glacial lake outburst flood (GLOF).

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Catastrophic glacial lake outbursts have occurred in many mountain ranges throughout the world and, in some instances, have caused extensive damage and loss of life further downstream. The HKH region is no exception. If climate warming continues, as is predicted, accelerated glacier thinning and retreat is likely. Thus, the danger posed by GLOFs will increase. The HKH region is also one of extreme seismic instability. Earthquakes could act as major triggers for glacial lake outbursts. Earthquake prediction is in its infancy and not likely to assist in GLOF risk assessment in the near future. Nevertheless, the earthquake hazard makes the identification of potentially unstable glacial lakes that much more critical. GLOF risk assessment has become an issue of great urgency.

Glacial lake outburst floods in the HKH

Awareness of glacial lake outburst floods in the HKH region is derived from the memories of local people and from incidentally documented evidence. However, the precise location, frequency, and actual scale of their effects are not adequately known. Scientific investigation has revealed that a GLOF occurred along the Seti Khola about 450 years ago. It produced a debris deposit, up to 50 meters deep, that mantled an extensive area of the Pokhara valley in western Nepal. It appears that glacial lake outbursts have occurred more frequently during the last fifty years, for example, the following.

On 11 July 1981, the diversion weir at the Sun Koshi Hydro-electricity Project, Nepal, was struck by a large flood and incurred significant damage. The flood also destroyed two bridges and extensive sections of the Arniko Highway, resulting in some US$ million in damages. It was later realized that the flood resulted from the outbreak of the Zhangzangbo (Boqu) glacial lake in Tibet, China. On August 4,1985, an outburst flood from Dig Tsho glacial lake in the Khumbu Himal, Nepal, destroyed the nearly completed Namche Small Hydel Project and caused additional extensive damage farther downstream. On October 7,1994, a GLOF occurred from Lugge Tsho, 90 kilometres upstream of Punakha Dzong in Bhutan; the resulting deluge along the Pho Chhu river caused extensive material damage and some loss of life. GLOF events can propagate for considerable distances downstream and are thus liable to cross international boundaries. This has implications both for warning and for assessing responsibility (if any) for loss of life and damage to property.

Despite the scale of the risk associated with a GLOF, mitigation is possible, for example through artificial lowering of the water level (draining) and installation of early warning systems. Furthermore, given adequate mitigation measures, the glacial lakes can be regarded as a form of water storage and valuable potential source of water and hydroelectric power.

ICIMOD and the study of GLOFs

ICIMOD embarked on studies of glaciers and glacial lakes in 1985, with an assessment of the Dig Tsho outburst. In 1999, ICIMOD started preparation of an inventory of glaciers and glacial lakes, and identification of potentially dangerous lakes, using a combination of remote sensing images and published maps. The survey of Nepal and Bhutan was completed in 2001 and later extended to selected watersheds in China (Tibet AR), India, and Pakistan, working in collaboration with the national institutions of the countries concerned. Potentially dangerous lakes were identified using criteria such as large and rapidly expanding lake size, rise in lake water level, activity of supra-glacial lakes, position of lakes in relation to moraines and associated glaciers, dam stability, glacier condition, and surrounding physical conditions. Altogether 8,790 glacial lakes were mapped, of which more than 200 were identified as potentially dangerous. The inventory is now being updated and extended to the entire HKH region.

More recently, methods for assessing and mapping the vulnerability of downstream communities have been developed and are being used to prioritize lakes of most concern. A 2009 study using remote sensing data and other information identified 1466 glacial lakes in Nepal of which six were classified as potentially dangerous and requiring detailed field investigation. Detailed field investigations were made of three lakes (Imja, Thulagi, and Tsho Rolpa). In all three, the immediate risk of dam break was found to be lower than previously reported, although they should be monitored regularly. The socioeconomic assessment showed a high risk of damage if an outbreak were to occur. Comparable investigations should be extended to other areas of the HKH region in collaboration with member countries.

Future outlook

As new glacial lakes are being created and existing ones continue to grow, the issues of risk assessment, early warning systems, and mitigation measures to reduce impact are becoming ever more important. It is vital to identify potentially dangerous glacial lakes and the risks they pose, and highlight the critical ones. Planners, policy makers, development workers, and scientists need to develop and implement appropriate mitigation measures including the implementation of early warning systems. Collaboration with local people is essential.

Given the enormous extent and poor accessibility of the HKH region, use of remote sensing is essential for identification of those lakes that require detailed investigation. A repeat monitoring system using time series satellite images is necessary to identify changes over time. Detailed glaciological and geotechnical field investigations of priority lakes are needed to determine the real degree of glacial lake instability, and socioeconomic assessment with modeling of the downstream flood path to discover the likely risk. Only then can effective preparedness and mitigation measures be implemented.

Overview of Local Perspectives on Water Resources and Water Management in the Khumbu Area, Eastern Nepal

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Introduction

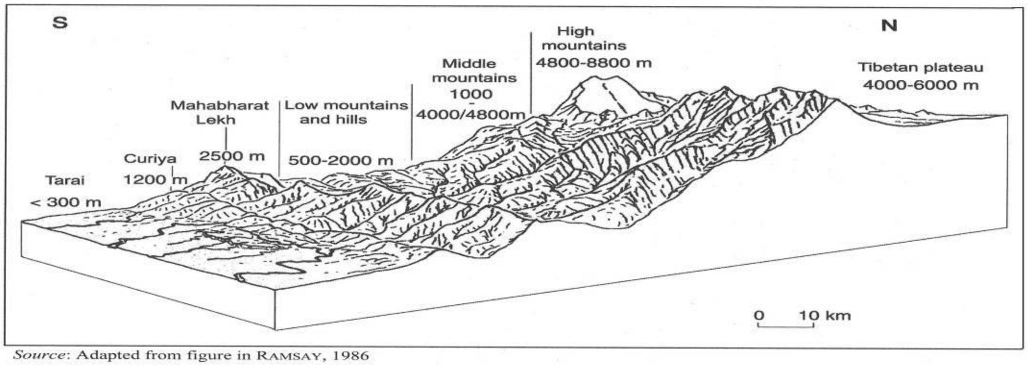
Mountain ecosystems have suddenly gained global attention because of receding glaciers and growing glacial lakes, which create new vulnerabilities and are, at the same time, the most spectacular indicators of climate change. But those visual impacts are only the tip of the iceberg, because more sensitive ones regarding the adaptation of populations are necessary to take into account. The focus on the analysis of water resources refers to the relationship between environment, humans, and the deities. The concept of "water" gives both a physical and a human approach to this study in the way it is necessary to analyze the hydrological system of the river but also to understand the traditional knowledge on coping and adaptive mechanisms to environmental changes. In addition, growing demands for water and hydro energy and other ecosystem services deriving from mountains have led to recognition of the need for more integrated visions addressing upstream-downstream interdependencies in Nepal.

A Global vision of the water resources stakes inside an overall project: Paprika

The interlinkage between the climatic and non-climatic drivers of change influencing the world's freshwater resources, as well as the high uncertainty regarding variation in precipitation patterns and other parameters influencing the hydrological cycle in mountains, are extremely difficult to predict and need to be better understood. An effort to address this questions is undertaken by a French research program ANR (National Agency of Research) called Global Environmental Changes which finances the 'Paprika' project: *"CryosPheric responses to Anthropogenic Pressures in the Hindu Kush-Himalaya regions: impacts on water resources and society adaptation in Nepal"*. One of the aims of the PAPRIKA project is to assess the change of water availability due to climate change and the impact of such a change for the populations and their uses of water. Being involved in an overall project is an opportunity for my research to benefit from multiples approaches and tools.

Usages of water related to geographical units

Studying water usages in the four main landscape units within the country (high mountains, middle mountains, low mountains and hills, and the Terai plain) is relevant in the sense that the origin of water differs in each unit (melting of the glaciers, melting of snow, and rainfall) and therefore variations of water availability for mountainous and downstream communities will have different consequences. The classification of different geographical units in Nepal proposed by J. Smadja (2009 [2003]) is particularly interesting for the topic of water, since it takes into account the main origins of the water used by people.



Source: Adapted from figure in RAMSAY, 1986

North-South profile of the Nepalese Himalayas
J. Smadja

Fig.1: Geographical Units of Nepalese Himalaya (for the needs of this study Mahabharat and Curiya are integrated into the low mountains and the hills) (Smadja, 2003)

Inside the Paprika project, the decision has been taken to focus on four units that are parallel belts located along the Himalayan range, and in each belt to choose one reference site. The hypothesis is that climate change will affect differently the various belts.

The origin of water in the High Mountain range

Since the project is pluri-disciplinary involving glaciologists and air chemists working with the Italian research center called Pyramid located on the way to the Everest base camp, the area of concern is situated according to a transect along the Dudh Koshi basin in Nepal. My research site is based on the high mountain belt for which the study occurred in the village of Pangboche, 4,000m, in the Solu-Khumbu District, Khumjung VDC (Village Development Committee) and part of Sagarmatha National Park.

The high mountains (from 4000 to 8800 m) are characterized by the presence of glaciers, low temperature, an arid climate in the interior valleys in the western part of Nepal located behind the high range of the mountains that blocks the monsoon rains (annual rainfall is 2 to 400 mm) and a semi-arid climate in the eastern part where some monsoon rains fall (one third of the 800 mm of annual rain in Pangboche). The water is then either in the state of ice (glacier, frozen torrent, permafrost), of snow falling during winter and beginning of spring, or liquid fluid when the temperature or stream turbulence permits it. So the flowing water used comes either from the melting of a glacier, the melting of snow, resurgence of groundwater, or running water in streams.

Approach and Methodology

The research approach focuses on villagers' perception of climate change and of the variability of water availability, and on the impact of such changes on people's practices. Furthermore, a diachronic and spatial approach to farming practices, to the uses of domestic water and to the socio-economic context include participant observation of one year in the village area. But the need of qualitative data is complemented by the study of climate variability and trends leading to the monitoring of Pangboche small watershed and on the collection of meteorological data (temperature and precipitation).

First results: Local perspectives on water use and management in Khumbu

The uses of water analyzed within this one year fieldwork campaign unlighted the most recent changes in Khumbu, especially the pressure on water resources due to tourism development. In fact the Sagarmatha National Park register 27% of increase in the number of entries during the last 10 years (from 21 570 to 32 124 tourists between 2000 and 2010). In order to answer to the new needs relying on water resource, the village of Pangboche is facing an increasing consumption of domestic water (supply of water by pipe inside local houses and lodges, flushing system in toilets), and a commercialization of water leading to new usages (production of hydroelectricity, shower in the lodges, watering of vegetables, purification of drinking water, water bottling). At a regional level, it seems that in the villages facing a lack of water we can observe some structured and collective organization of water management, whereas in villages where the present availability of water –with the present water use- does not lead to any major conflicts (as in

Pangboche case), the water use and management are informal and leaded by individual practices and initiatives.

Several actors are involved in water management and facing the diversification and growing of water issues starting from local level (in some cases water committees, private initiatives of lodge owners, monasteries), to institutional level (the Sagarmatha National Park since 1976 and Buffer zone committee since 2002, the Village Development Committee under Nepal Government), unto international level (INGO's, sponsorship from tourists). The involvement of a multiplicity of actors leads to a complex perception and concerns of environmental changes.

Therefore, tourism has been a new catalyst of change regarding water resources in the Khumbu area and the climatic irregularities are an additional challenge to these current transformations. In fact, any variation in the precipitation pattern (either snow or monsoon rain) have important impact on plant growth, and cropping activities (for potatoes cropping but also grass harvesting).

Glaciers and Glacial Lakes under Changing Climate in Pakistan

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Abstract
The Himalayas, Karakoram, and Hindukush lofty mountain ranges meet each other in Pakistan, hosting more than 5,000 glaciers, which feed water to the Indus River System together with summer monsoon. Due to global warming, frozen water resources have been losing their reserves at an unprecedented rate, not only reducing the ice mass but increasing the number and extent of glacial lakes. Glacial Lake Outburst Floods (GLOFs) are the devastating mountain hazards which have started occurring with increased frequency during recent years. An alarming increasing temperature trend in northern parts of Pakistan in the last decade, which surpassed all the past records, has enhanced the snow/ice melt rate and given rise to a lake formation process – some of which is potentially dangerous for outburst. Global temperatures have been increasing at a higher rate than predicted by GCMs in 1990s and this rise is associated with unprecedented extremes. An initiative of The Mountain Institute (TMI) toward Global Glacial Lake Partnership is a step forward to manage dangerous lakes to mitigate the potential risk due to their outburst under expected climate change.

Key Words: Glaciers, Glacial Lakes, TMI, Passu Lake, Global Glacial Lake Partnership, GLOF

Introduction
Pakistan is located in South Asia between 24⁰-37⁰N latitude and 66⁰-77⁰E. It hosts the triple point (junction) of three world famous mountain ranges – Himalayas, Karakoram, and Hindukush – in its north. There are more than 5,000 glaciers feeding the Indus from 10 sub-basins through different tributaries ranging from tens of meters to more than 70 km long. Over this glaciated domain, there are about 2,500 glacial lakes formed due to glacier melt waters and 25 of them were declared potentially dangerous for GLOF (ICIMOD, 2005). The GLOF events are catastrophic as huge loads of debris and mud flows downstream sweeping the infrastructure, houses, and crop-lands, resulting in scores of life losses if it happens without any alert signal. For mountain populations, GLOF is the greatest hazard which is being reinforced by climate change in terms of frequency and vulnerability. Booni Gole Glacier located near Chitral in Hindukush mountain range generated outburst flood in July 2010 was triggered by monsoon downpour and caused huge erosive damage to agricultural land and human settlements along the flow channel. It used to store water under the terminus of the glacier and produce surge either by accelerated melting of snow/ice or by intense rainfall. Due to steep slope downstream, the carried loads of mud, debris, including heavy boulders, gain momentum and cause heavy losses to land, settlements, and infrastructure. Passu Lake outburst had also followed a similar mechanism.

Climate Change
Global warming due to human activities has been affecting all aspects of life, posing serious challenges to the availability and utilization of natural resources. Rise in temperature registered during the first decade of the 21st century has been two times higher than was anticipated. According to the World Meteorological Organization (WMO, 2011) statement on status of climate, the first decade (2001-2010) is the warmest decade recorded over the globe and 2010 ranked as the warmest year (+0.53⁰C), followed by 2005 (+0.52⁰C) and 1998 (0.52⁰C).

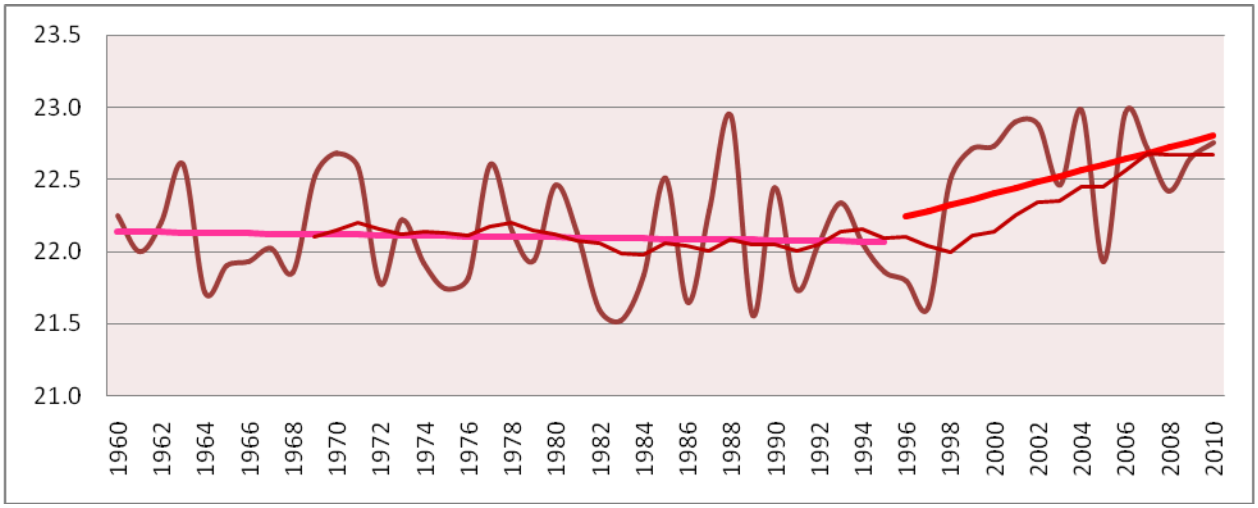

Figure 1: Graph showing temperature records of meteorological observatories(1500-2900masl) located in northern mountains of Pakistan from 1961 to 2010. Last decade has shown a sharp rise. (Source: PMD)

Pakistan is no exception and warming trend in northern mountains is double as compared to the lower elevations. Sharp increase in temperature during last decade can be seen in Figure 1. A study conducted by Chaudhry et al., 2009 indicated that Pakistan experienced a 0.76◦C rise in temperature during last 40 years. However, the increase in temperature in the mountain environment hosting thousands of glaciers was recorded as 1.5◦C during the same time period. Occurrence of precipitation in the form of rainfall up to 4,000 m above mean sea level is a common feature in mountainous terrain where it was rare in the past. The study further pointed out that the frequency and persistence of heat waves in glacierized mountains has increased drastically causing rapid melting and sudden discharge of bulk of water to terminal lakes of glaciers increasing the risk of outbursts.

Glacier Melting

Most of the world glaciers are subjected to depletion with a few exceptions (IPCC 2007) posing serious challenges to water security. Shroder et al., 2007 found that the loss of significant glaciers in Afghanistan and Pakistan may become progressively more serious unless warming generates greater marine evaporation that augments precipitation. The global retreat of glaciers is striking and it is appropriate to study the dynamic behavior of glacial fluctuations interaction of atmosphere-cryosphere approach (Kaser, 2001; Wagnon et al., 2001). Temperature analysis revealed that the snowline has shifted about 1 km higher than its location 25 years before, resulting in upward migration of animals and plants species (Rasul, 2006). The effects of global warming in mountain areas are visibly manifested by shrinking of mountain glaciers and reduced snow cover duration (Barry, 2002). However, Hewit (1998) reported the widespread expansion of large glaciers in the central Karakoram, accompanied by an exceptional number of glacier surges. Rasul et al., 2008 reported that the frequency and intensity of heat waves have significantly increased over the southern slopes of HKH along with an unprecedented increasing trend of annual mean temperatures over this heavily glacierized region.

Most of the glaciers in Pakistan's geographic limits are debris-covered and the melting rate differs according to the thickness and type of debris in addition to the other factors. Pakistan Meteorological Department (PMD), in collaboration with several international research groups, has been recording in-situ meteorological and glacier data by high altitude Automatic Weather Stations (3000-5000 amsl) installed over the glaciers and through field measurements since 2006. At present, 10 large glaciers are being studied in Karakoram and two in Hindukush range. However, the extensive research is focused on two major glaciers Baltoro (heavily debris-covered) and Passu (relatively clear). The results of ablation experiments conducted on Baltoro Glacier are shown in Figure 2.

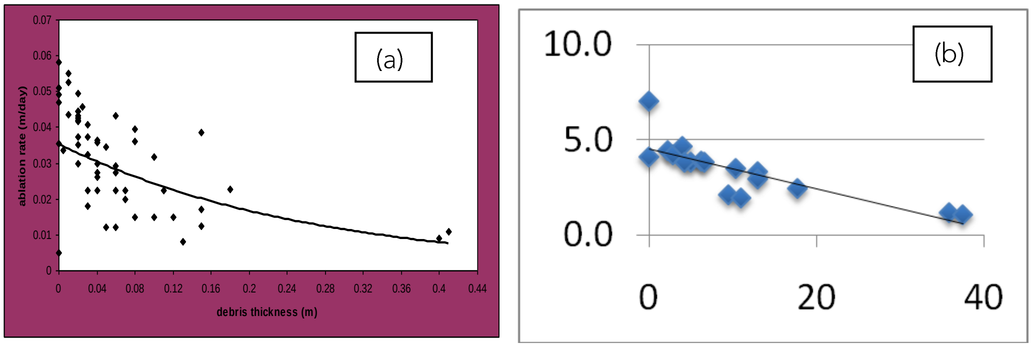

Figure 2: Ablation experiments conducted over the surface of Baltoro Glacier by installation of stakes form to study the melt rate per day against thickness of debris cover during summer (a) 2008 and (b) 2011.

During the field visits, it was noticed that a huge amount of water was held under the ice bulk near the terminus (tongue) of many glaciers, especially in the case of Booni and Passu glaciers, which used to cause mysterious outbursts in the past. As such, a large volume of water ever increasing was not visible, and therefore caused serious damages downstream to human lives, settlements, as well as infrastructure.

Candidate Pilot Project in Pakistan at Passu Lake

Introduction

Passu Lake is a glacial lake located at the terminus of 38 km long east-west oriented Passu Glacier, which suffered at least two outbursts in last two decades, destroying a bridge on Karakoram Highway and several houses of Passu village settled on the right bank of the Hunza River (a tributary of the Indus which is partially blocked due to landslide dam January, 2010 called Ata Abad Lake).

Outburst Mechanism

Although the Passu Lake has natural drainage and apparently there is the least probability of its outburst, it did happen, mysteriously causing huge losses. On investigation, it was disclosed that under the fragmented tongue of the glacier, a large volume of water used to store which continues to discharge to the nearby lake under normal conditions. The generation of massive flow in these last two events was associated with a 37 mm rainfall event in two hours and due to accelerated snow/ice melt from a 14 day-long heat wave (day highs>33°C). During the past outburst events, very heavy loads of mud as well as debris (mixed with huge boulders) flowed downstream under the action of gravity flow destroying the structures on the way.

Existing Monitoring

Pakistan Meteorological Department has installed two AWS with the financial assistance of ICIMOD in the accumulation and ablation zones of the glacier to monitor the gradient flow and drift velocity along with the ablation rate assessment under different conditions. Hydrometeorological monitoring equipment has also been operational on the lake site measuring lake discharge since 2010. There are two meteorological observatories located in the radius of 15km around the Passu Lake at elevations 2,815 m and 2,975 m respectively above the mean sea level.

A non-governmental organization known as FOCUS Humanitarian Assistance of the Agha Khan Foundation has been very active in the mountainous region and an effective connect for community involvement may become an active partner in GLOF monitoring and warning activity. This could be a great field support to mobilize the community, raising awareness and giving them the sense of ownership.

Data Sharing Policy

TMI and ICIMOD may establish a pilot project with further installations for a GLOF early warning system at Passu Lake in Pakistan. Data sharing for modeling and operational activities is not restricted following the WMO mechanism.

References

Barry, R. G., 2002: Changes in Mountain Climate and Glacio-hydrological Responses. Mountain Research Development. 10, PP. 161-170.

Chaudhry, Q. Z., A. Mahmood, G. Rasul and M. Afzaal, 2009: Climate Change Indicators of Pakistan Meteorological Department, Technical Report No. PMD 22/2009.

Hewitt, K., 1998: Glaciers Receive a Surge of Attention in the Harakoram Himalaya. Ecos, Trans. Amer. Geophys. Union. 79, 104-105.

IPCC 4th Assessment Report 2007: Available online

Kaser G. 2001. Glacier –climate interactions at low latitudes. Journal of Glaciology 47: 195–204.

Rasul, G. and Q. Z. Chaudhry, 2006: Global Warming and Expected Snowline Shift along Northern Mountains of Pakistan. Proc. of 1st Asia CliC Sympos. Yokohama, Japan.

Rasul, G., Q. Dahe and Q. Z. Chaudhry, 2008: Global Warming and Melting Glaciers along Southern Slopes of HKH Range. Pakistan Journals of Meteorology, 5(9), 63-76.

Shroder Jr, J. F., M. P. Bishop, H. N. N. Bulley, U. K. Haritashya and J. A. Olsenholler, 2007: Global Land Ice Monitoring from Space (GLIMS) Project Regional Center for Southwest Asia (Afghanistan and Pakistan). Development in Earth Surface Processes No. 10 "Mountains Witnesses of Global Changes". Elsevier Publishers, pp 187-207.

Wagnon P, Ribstein P, Francou B, Sicart JE. 2001. Anomalous heat and mass budget of Glaciar Zongo, Bolivia, during the 1997/98 El-Ni˜no year. Journal of Glaciology 47: 21–28.

WMO Statement on World Climate 2011. Available online

Adapting to Climate Change in the Andes: Preliminary Results of The Mountain Institute-USAID program *Peaks to Coast*

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Background

Peru (28.8 million inhabitants) is listed among the most vulnerable countries in the world to the impacts of climate change, due to a combination of several bio-physical and social factors. They include (i) the loss of nearly 25% of the surface area of the country's 19 tropical glacier ranges during the last 35 years, with smaller ranges having lost a higher proportion, (ii) the fact that the poor are concentrated in rural areas (60% of the total), a sector that depends on rain-fed and irrigated agriculture for its subsistence and is thus highly exposed to climate change, and (iii) the fact that 68% of Peru's population lives in the narrow western coastal belt, one of the driest regions of the planet that containing cities such as Lima (with 30% of Peru's total population) that are totally dependent on water flowing down from the Andes (UNDP 2010).

These changes and increasing variability in climate are taking place at a time of economic expansion in Peru. The annual growth rate of Peru over the last decade has fluctuated between 5% and just over 9%, brought about by a large expansion of the mining sector in the highlands and a steadily growing demand of water for hydroelectric power generation (providing around 58% of the electricity), irrigation in the coast, and urban and industrial consumption of water in large cities like Lima. Demand for hydroelectric power is expected to grow 100% by 2030. Over 80% of Peru's gross domestic product is generated in the arid coastal area of Peru, oasis-like valleys that are entirely dependent on water that precipitates and is regulated by natural and artificial means in the mountains.

While coastal region populations are and will be impacted by the loss of glacier-fed freshwater during the long dry season (May and October), they are in a way less vulnerable than the rural poor who live below the vanishing glaciers to the extent that coast populations have more financial, technological, political, and other resources to adapt to negative impacts in the provision of water. Rural highland people are organized largely in "peasant communities," a land tenure institution that ultimately retains collective property of the land but allows in practice the private, inter-generational usufruct of the land by smallholders (often planting less than one hectare per year in dispersed small plots of a few hundred square meters each). In this highly unpredictable environment, Andean communities developed a complex agrarian civilization that included the domestication of tubers (three species of potato and over 3,000 cultivars), grains, and roots. Their adaptation to a highly unpredictable environment included the diversification of crops, the dispersion of plots at multiple altitudes and within the geography of their communities, mutual social support systems like product and labor exchange traditions, post-production technologies such as the drying of potatoes to create food reserves, and notably, the construction of irrigation systems, terraces, and other water management technologies that built cultural landscapes in grandiose scales. In the Santa River watershed, for example, one of The Mountain Institute's project sites, 70% (47,000) of the users of water are highland users, and only 30% (20,300) lowland users in the coastal areas (Hendrick 2008, 2010).

Unless adaptation practices and policies are developed and/or improved, an accentuation of the current tendency of social conflicts over water can be predicted with confidence. Currently, 50% of all major social conflicts in Peru over the last five years have been environmental in nature, with water being the main resource contested (Recharte 2010).

In summary, Peru illustrates in unique ways the challenge of developing adaptation strategies that respond to the rapid recession of glaciers in mountain environments. While it is not possible to draw any direct extrapolation, the experience gained may help other regions of the world, such as the Hindu-Kush Himalaya, which are undergoing similarly rapid transformations in the natural systems that affect their water regimes.

The Peaks to Coast project

Through a cooperative agreement with USAID Peru, The Mountain Institute is implementing a three-year project entitled "From the Glaciers to the Coast: Building Climate Change Awareness and Resilience in the Ancash and Piura Watersheds of Northern Peru." This initiative, referred to in short as "Peaks to Coast," is designed to respond to the social, economic, and political contexts described above. Peaks to Coast emphasizes the need to develop specific adaptation strategies to reduce vulnerability to climate change in the broader context of watersheds, features that not only connect water but which contain a diversity of social actors and institutions. The project focuses on the overarching strategy of conserving high mountain ecosystems, such as the *paramo* (humid mountain grasslands), the *puna* (semi humid grasslands), high altitude cloud forests (e.g. *Polylepis spp*) and alpine lakes and wetlands that retain and regulate water during the dry season.

Promoting the conservation of mountain ecosystems that regulate water is a "no-regret" response in the sense that, even if the latter is not sufficient in itself, it still creates benefits for the water cycle, supports animal productivity, enhances wildlife diversity, preserves the value of landscapes for non-intrusive economic uses like ecotourism, helps raise local capacities for the democratic management of natural resources, and increases the political visibility of otherwise marginal populations. The promotion of watershed conservation is also underlain by the shared goal of promoting cooperation among and between economic sectors, social actors, and different levels of government. This broad strategy of cooperation is a prerequisite that complements other water management interventions, such as the construction of reservoirs or even more efficient irrigation systems that require clean water.

The Peaks to Coast project is implemented in two highland locations of Peru: (1) Ancash, a heavily glacierized range that has lost nearly 30% of its surface area since the 1980s, and whose glaciers feed the Santa River basin (~12,000 km^2); and (2) Piura, the lowest section of the entire Andean range of South America that does not contain glaciers. The alpine landscape is dominated by paramo grasslands that regulate water for the Chira basin (~12,000 km^2). Both regions are characterized by smallholder traditional crop production for subsistence and poverty in the upland sections, while their coastal areas below show strong economic growth in the agricultural export sector and market based economies.

The design of the Peaks to Coast project was largely influenced by the presentations, discussions, and priority recommendations that came out of the international conference "Adapting to a World Without Glaciers," an interdisciplinary event that gathered academic researchers, practitioners, and policy makers in Lima and Huaraz in June of 2009 (TMI 2009). Key elements of the strategy of Peaks to Coast, as influenced by the priority recommendations of the 2009 workshop, include:

- The need to decentralize adaptation strategies to the geographically lowest possible scale empowering local social actors
- Rural communities that own and manage mountain ecosystems must be the drivers of adaptation strategies
- The development of a "model" (best practices and tools) to develop adaptation strategies that increases the capacity of local communities and local municipal governments to cooperate in the management of their territory.

The Peaks to Coast project aims to improve the capacities of: (1) rural communities to understand their vulnerability to climate change, design adaptation responses, and communicate to local governments the value of sustainable uses of the puna, paramo, and other alpine ecosystems, and (2) municipal governments to develop policies that support local responses to climate change in their territory.

Peaks to Coast facilitates actions to shorten the social and political distance that separates rural communities, who have ownership and management responsibility of mountain ecosystems, from municipal governments that have the resources and legal mandate to promote sustainable development. Active citizen participation of communities in local governments, and promoting projects that incorporate analyses of vulnerability, contributes to sustainability of adaptation strategies.

Local engagement in Climate Change Adaptation

The Peaks to Coast project applied USAID's methodology to facilitate analysis of vulnerability to climate variability and change (USAID 2009). Using this approach, the project engaged mountain communities, lowland water users, and local governments to analyze their vulnerability to climate change. In all cases, a willingness to engage in the process reflects the concern that stakeholders have about climate and climate change, but equally for other non-climatic contextual factors that affect their development as well.

The mountain communities of Ancash have clearly identified changes in climate as a factor that affects their natural resources, livelihoods, and existence. They note specifically the alterations in the onset and expected patterns of precipitation, the tendency to more extreme temperatures, and the loss of glaciers as worrisome changes that threaten their means of life (Zapata and Dourojeanni 2011). Similarly, lowland water user groups perceive the potential threat of losing glaciers, more extreme precipitation events, and the degradation of upland ecosystems as a threat to their means of life.

In the process of engaging in climate change adaptation strategies, all groups took the step of advancing "no-regret" adaptations. For instance, the community of Huasta in Ancash engaged in a two-year process to declare a section of their native *quenual* (*Polylepis spp*) forests a legally recognized private conservation area. A second community in Ancash engaged in planning and applied research on the impacts that different range management practices had in the hydraulic "yield" of grasslands and water quality for irrigation, to the extent that results are connected to a keen interest in improving the productivity of their livestock and developing irrigation systems. Lowland stakeholders in Ancash and Piura also engaged in the process of climate change adaptation, identifying improvement of their knowledge of the watershed and climate change impacts as one of their adaptation measures. The Ancash lowland site became more active in forums dedicated to integrated water management. Both sites are developing small interpretation centers to improve awareness of integrated management of their basins and climate change. For example, the water user association San Lorenzo (JUSAL), the Piura lowland site in the coast that irrigates with water from the highland Chira basin, committed financial support to the conservation effort of highland groups protecting the paramo ecosystem.

At the level of highland municipalities located in the upper sections of the Santa basin in Ancash, the process of increasing awareness of climate change, and the unique role of upland ecosystems, led to the political will and commitment of mayors to cooperate among themselves to establish a commonwealth *(mancomunidad municipal*). The commonwealth is dedicated to the objective of collectively supporting each other in the sustainable use of highland ecosystems, development of water infrastructures, and other potential responses to climate change. Not unlike the case of rural communities, climate change became a catalyzer for cooperation among municipalities. As a result of these process, 10 municipal governments have established legally recognized commonwealths that they expect will help them bring more and larger investments in water infrastructure projects. Although municipalities are still in the process of developing adaptation plans, they have already established a legal mechanism for the consultation of rural development plans (the mechanism is called "citizen conference") that involves the heads of all 19 rural communities in the commonwealth. Thus, the commonwealth is already creating better conditions for rural development and scales of economy in the future implementation of other adaptation strategies.

The process of fostering the participation of women in adaptation strategies has been focused on increasing the capacities of councilwomen in their municipalities, and on improving knowledge of their rights, as authorities of the legal and administrative norms, through increased and awareness of climate change. The hypothesis is that through this process, councilwomen will become leaders that know and represent the interest of rural women in development projects and particularly actions that incorporate an analysis of how climate change affects women.

Developing linkages with national and international research groups has been important because it is a source of valuable and legitimate information that supports decisions. However, more detailed and in-depth information will be required to design effective adaptation strategies that are based on a profound understanding of the climatic and hydraulic functions of the upland territory.

Conclusions

(1) The Peaks to Coast project has gained experience in incorporating climate change adaptation actions by taking a systemic upland-lowland approach. The positive aspect of this approach is that by working in the entire system, and by engaging the full array of stakeholder interests, climate change adaptation strategies are more sustainable. The downside of taking such a broad approach is that the level of complexity can be overwhelming. Nonetheless, this systemic approach is necessary.

(2) Working on adaptation responses in a complex basin system is made more manageable to the extent that facilitation focuses on improving conditions for the direct participation of local, organized groups of citizens in existing government institutions. For instance, the upland commonwealth, in the particular case of Peru, has proved to be the one key mechanism in which to focus all efforts.

(3) For the organization that acts as the main facilitator of climate change adaptation strategies, first the scope of the upland-lowland system and the key mechanism must be defined, followed by improvements in the tools and rules that should guide the process by which a local community of practice is grounded in local society. Adaptation to climate change is clearly not a single intervention but a continued learning process. If we take an optimistic perspective, the urgency of responding to climate change may be finally creating interest among all stakeholders to promote adaptive management.

Community-based Participatory Research in Imja Valley in Nepal's Sagarmatha National Park and Buffer Zone, Solu Khumbu, Nepal

Ang Rita Sherpa
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The Mountain Institute (TMI) hosted the first Andean-Asian Glacial Lake Expedition in the Mount Everest (Khumbu) Region in Sagarmatha National Park and Buffer Zone, Solukhumbu, Nepal from September 4-22nd, 2011.

More than 30 international technical and social scientists participated in the expedition to observe the potentially dangerous glacial lake at the top of the world and the great peaks of Himalayas. This is the home of Sagarmatha National Park and Buffer Zone, a World Heritage Site.

The Andean-Asian Glacial Lake Expedition entailed three weeks of field-based research in an area where, over the years, global climate change has disproportionately impacted the high mountain environment.

The expedition hosted physical and social scientists from different regions of the world, including the Andes, Hindu-Kush-Himalaya, Central Asia, Japan, North America, and Europe. During the 18 days in the field, both the physical and social scientists conducted formal and informal discussions about climate change, glacial lakes, and climate adaptation. The main focus of the discussions was the unprecedented rate of glacial retreat that has been noted by high-altitude mountain communities and is a major concern due to impacts in the Himalayan glaciers.

Glacial retreat in high-altitude landscapes is one of the most visible signs of global warming. There are important implications for freshwater flow, agriculture, biodiversity, and health. Seventy-five percent of the world's fresh water is stored in glaciers, and there are predictions that climate change will cause some of the world's largest glaciers to melt dramatically in the coming decades. The implications for freshwater availability are significant.

The Andean-Asian Glacial Lake Expedition's goal was to observe glacial landscape changes in the Imja Valley. During the last two decades, the glaciers in the Khumbu region, particularly Imja Glacier, have provided a unique opportunity to study climate change and its potentially dangerous effects, such as glacial lake outburst flooding (GLOF). This exchange and collaborative expedition used community-based participatory research to convene with local people, with the intention of understanding the issues, concerns, and solutions expressed by the community. Such community-based research is unprecedented in the Khumbu region. This collaborative approach equitably involves the local communities and other stakeholders who will be affected during the research process, and recognizes the unique strengths and perspectives that each stakeholder brings.

The expedition met with the local community before arriving at Imja Lake Base Camp, where the expedition camped for three days. The local Sherpa community in Dingboche welcomed the entire team with a festive song and dance at the Khumbu Alpine Conservation Council (KACC) building. During the meeting with the local community, Sherpas from Shomare, Dingboche, and Chhukung, who live in the floodplain of the much publicized Imja Lake (known locally as Imja Tso), expressed concern about the possibility of a GLOF, which could destroy approximately 30 houses and 30 km of trail that exist below this glacier.

At the meeting, the local community expressed frustration that previous research discussed the potential of a GLOF event of Imja Lake without providing tangible solutions. The community explained that previous researchers had not been responsible in reporting their findings, and had published alarmist reports rather than measured responses that focus on action-based planning. The community also expressed their desire that no further non-applied research of the lake be allowed in the Khumbu area. Instead, research focused on practical mitigation options should begin immediately. The community discussed the potential to drain water at the Imja Lake outlet and to use it to generate micro-hydropower. By developing hydropower from the water outlet of the glacial lake, and through the conservation and restoration of mountain watershed, the community hoped that we can counter the impacts of warming trends by creating cooler environments, saving biodiversity, protecting fragile alpine ecosystems, and protecting water supplies.

In response to the community consultation meeting at the KACC in Dingboche, the expedition members invited the local community representatives to visit the Imja Lake site for a briefing of the lake conditions. The expedition team, as well as the local community, felt a joint observation was the best way to inform and share information. During the community's visit to Imja Lake, Dr. Teiji Watanabe, from Hokkaido University of Japan, and Cesar Portocarrero, a Peruvian glaciologist from Peru, were asked to brief the local community. The briefing discussed the glacial lake's present condition, practical experiences in glacial lake control, risk mitigation, and glacier management. The local community was informed that although Imja was a glacier in the early 1960s, climate change has caused the glacier to retreat, leaving behind a lake with a volume of more than 35 million cubic meters of water that is contained by an unstable terminal moraine of loose boulders and soil.

In order to further the expedition's goals of community-based participatory research at Imja Lake, the expedition broadcast a daily live blog throughout the entire journey with photos, videos, and stories. On the blog, members of the expedition posted daily updates so that the rest of the Sherpa community in the alpine zone as well as people around the world could follow the events of the expedition, read about the challenges of working in remote mountain landscapes, and learn about the trials faced by the local mountain people who have been among the first to feel the impacts of climate change.

The Sherpas are grateful to the participants for showing great concern about Imja Lake. The Sherpas of the Khumbu region are also grateful to Dr. Alton Byers and The Mountain Institute for hosting scientists from around the world who not only understand the risks of glacial lake outburst floods, but also show an interest in meeting and discussing the risks of Imja Lake with the local communities. According to the Sherpa community, TMI was the first organization to involve locals in field research. The Sherpas hope that other scientists will follow The Mountain Institute's legacy in community-based participatory research. The Sherpa community also hopes that there will be positive recommendations to the Nepali government as well as donor agencies, and that a positive, action-oriented program to mitigate the threats of glacial lakes will be developed based on the observations from the expedition and during the workshop that took place upon returning to Kathmandu.

GLOF Risk Mitigation of Tsho Rolpa: Positive and Negative Aspects

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Tsho Rolpa glacier lake is located about 110 km north-east from Kathmandu. The lake, situated at the headwaters of the Rolwaling River Valley, is the largest moraine-dammed glacial lake in the Nepal Himalaya and is the only lake which has experienced mitigation measures so far in Nepal. The lake is located at an elevation of 4,580m a.s.l. Tsho Rolpa is a moraine dam lake and fed by Trakarding glacier, which itself is fed by several other big glaciers, including Trolambau glacier. Dig Cho Lake, which burst out in 1985, is located across the Tashi Lapcha ridge in the adjacent Khumbu valley.

Some of the hazard characteristics of the lake are: (1) existence of hanging glaciers, although fortunately they are getting smaller and retreating further away from the main lake; (2) heavily ice-cored moraine dam, which is gradually melting and weakening the moraine; (3) frequently calving ice cliff at the terminus of Trakarding glacier, potentially causing a large displacement wave; and (5) existence of some high altitudes lakes, outburst of which can cause cascading effect and cause outburst of Tsho Rolpa and large size of the lake and volume of the water stored. Tsho Rolpa Lake was most recently measured in 2009. According to this measurement, the lake area was 1.54 sq km, while in 1955 it was 0.22 sq km. The measurements made at various times and reconstruction made based on various maps and satellite images suggest that the lake has grown rapidly to its present size.

Some comparisons with Imja Lake are made, which highlights that the GLOF hazard in Tsho Rolpa is significantly higher. For example, Tsho Rolpa moraine dam has a very low freeboard of 5 m compared to 10 m of Imja Lake. The width of the moraine dam at Tsho rolpa at the narrowest location is only 50 m compared to 560 m wide moraine dam of Imja lake. Further the moraine dam of Tsho Rolpa is about 150 m high while that of Imja Lake is 50 m. Furthermore, the lake area of Tsho Rolpa is 1.5 times larger than Imja Lake and the volume of water stored in Tsho Rolpa is 2.4 time more than that in Imja Lake.

There is a remarkable difference in the vulnerability of downstream of the two lakes. In Rowaling and Tamakoshi valley, infrastructure development is taking place rapidly. Several new hydropower projects are coming up. A GLOF from Tsho Rolpa in the future could have significant impact on infrastructure downstream. Infrastructure development in the downstream of Imja Lake is not extensive, whereas a potential GLOF from Imja could have a major impact on the tourism sector.

Open channel constructed on the moraine dam of Tsho Rolpa lake (left) and early warning station establish in the downstream of Tsho Rolpa (right)

The preliminary studies of Tsho Rolpa were conducted by Dutch students and researchers, which revealed that Tsho Rolpa was dangerous and had to be lowered using the siphons. In May 1995, test siphons were installed in the southwestern part of the end moraine, which became successful as a test of the technique. Later, There were studies on GLOF by WECS. More detailed qualitative and quantitative work was done with support from the Japan International Cooperation Agency (JICA). A study on debris flow and hazard assessment was carried out in 1994. These studies indicated that Tsho Rolpa is a dangerous lake and immediate actions need to be taken. After 1995, GLOF studies were shifted to DHM and, after a study by RGSL, it was declared that it was very likely that Tsho Rolpa will burst, bringing a lot of destruction to Khimti hydropower downstream. This caught a lot of media attention at that time. In August 1997, a project formulation mission was organized, which suggested constructing an open channel through the end moraine to lower the lake level by 20 m in a phased manner, the first phase with a 3 m lake level lowering. The government implemented the first phase with financial support from the Dutch government and the lake level was successfully lowered by 3 m in 2000. The lake lowering system has been functioning satisfactorily to date.

Prior to the construction of the open channel, a meteoburst based early warning system was established downstream of Tsho Rolpa in 1998 with financial support from the World Bank. This system worked well in the first few years. In 2002, a small flood washed out the GLOF sensor, which could not be repaired in Nepal. Some parts of the early warning system, such as solar panels and batteries, started disappearing, probably taken away by local people. Later, when the government started constructing the road, several of the warning stations were dismantled and removed. The early warning system is now out of function.

The Tsho Rolpa lake has experienced two intervention measures, among which one can be considered successful while the other unsuccessful. Collaboration with donor agencies was critical to the rapid deployment of measures once the threat from Tsho Rolpa was identified; equally important was the coordinated effort of a range of government departments. The installation of test siphons at the lake and of the manual early warning system, administered by the Nepalese army, was a coordinated effort led by the Department of Hydrology and Meteorology, with support from the Nepalese army, Nepalese police, Ministry of Home Affairs, and Department of Water Supply. By engaging scientists in the policy process, the government also ensured that the project would be implemented on a sound scientific and technical basis .

Community engagement also was effective during the implementation phase, with local people employed to build the physical structures to lower the lake level as well as to build the early warning systems. For a long time, the VHF radio at the lake site had been the villagers' only means of communication; the early warning systems were thus a key factor in helping establish the project's importance to the community.

The early warning system did not have further donor funding for continuous support. People downstream didn't realize what the support was for. There was huge communication gap to the communities to inform them and make them aware of the benefit. This failure of the early warning system can be attributed to an absence of maintenance funding, as well as the loss of awareness and concern by local communities, who seem to have forgotten about the threat of a glacial lake outburst . Inadequate ongoing public education about the risks of floods and the lack of engagement with local villagers through training programs in the use and importance of the early warning system may explain the loss of public support and the destruction of the system. The deteriorating security situation in Nepal and difficulty of maintenance is also to be blamed to certain extent.

The case of Tsho Rolpa has shown that GLOF mitigation measures need continuous follow up. Beside the main project activities there should be some elements to attract the local people. Local participation/communication/ awareness is a must for the sustainability of any kind of project. Tsho Rolpa is still a highly dynamic lake. The hazard and vulnerability levels are still very high. Therefore, regular monitoring is highly important.

Bibliography

Matambo, S.T. and A.B. Shrestha: 2011, "World Resources Report Case Study. Nepal: Responding Proactively to Glacial Hazards," World Resources Report Washington DC, Available online at http://www.worldresourcesreport.org/case-studies/nepal-responding-proactively-glacial-hazards.

Rana, B., Shrestha, A., Reynolds, J.M., Aryal, R., Pokhrel, A. and Budhathoki, K.: 2000, "Hazard assessment of the Tsho Rolpa Glacier Lake and ongoing remediation measures," Journal of Nepal Geological Society 22, 563-570.

Reynolds, J.M.: 1999, "Glacial hazard assessment at Tsho Rolpa, Rolwaling, Central Nepal," Quarterly Journal of Engineering Geology 32, 209-214.

Shrestha, A.B., Rana, B., Aryal, R. and Pokhrel, A.P.: 2001, "Hazard assessment and remediation work at Tsho Rolpa Glacier Lake, Rolwaling Himal, Nepal," Journal of Japanese Society of Civil Engineers 86, 72-75.

Shrestha, A.B.: 2007, "Tsho Rolpa, Seven Years After Mitigation Efforts," Asia Pacific Mountain Network Bulletin 8, 6-8.

Flood Risk Reduction in the HKH

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Based on OFDA CRED international disaster database analyses, disaster assessment in the Hindu Kush-Himalayas (HKH) for the last 30 years (1979 to 2008) reveals that 36% of all disasters are represented by floods, followed by epidemics. Floods are recurring with an increased frequency and with an increased magnitude in the HKH region – for example, the recent 2010 floods in Pakistan, which killed more than 2,000 people and left 20 million affected. Climate change further poses an additional challenge to this recurring disaster. There are various types of flood disaster in the Himalayas, namely riverine floods and landslides, glacial lake outburst floods (GLOF), flashfloods, and landslide dam outburst floods. Riverine floods are slow-rising and cause inundation. Flash floods consist of a rapid rise and fall in water level and discharge, coming very rapidly over a short duration of time and mainly in the tributaries in the mountainous areas. Community preparedness is key to minimizing flood disasters through early warning systems. All types of floods, including GLOF, are transboundary in nature with great consequences in terms of loss of lives and livelihoods in the downstream areas. Usually the elderly, women, and children are those that are most impacted by flood disasters.

Flood risk reduction includes structural and non-structural measures. Structural measures refer to physical construction such as dams, flood detention basins, river training, flow diversion, etc.; non-structural measures include flood risk modeling, education, training and awareness, improved policies for land use zoning, and effective early warning systems. An effective and low-cost non-structural measure is an end-to-end flood forecasting and warning system. An end-to-end flood forecasting system includes a chain of activities from data collection, acquisition and transmission, modeling, decision-making, and communicating it to end-users and action on the ground.

Floods do not recognize national boundaries, and early warning and management and mitigation of floods can only be accomplished with strong, basin-wide cooperation. In the HKH region there is a lack of exchange of timely real time data, especially across national boundaries. There is a diversity of technical capacity and scientific knowledge in the region providing an opportunity to share knowledge and experience amongst each other for better flood risk reduction. There are some existing bilateral agreements and treaties, but a regional framework is just emerging. Flood forecasting and timely and accurate warnings across transboundary basins are essential for saving lives and property. ICIMOD, in collaboration with the World Meteorological Organization (WMO) and regional partners, is facilitating regional cooperation through establishment of a Regional Flood Information System in the HKH region (HKH-HYCOS) with specific focus on the Ganges-Brahmaputra-Meghna and Indus river basins. The HKH-HYCOS has four components: framework for cooperation, regional flood observation network, regional flood information system, and training and public awareness. The other initiative of ICIMOD is application of satellite-based rainfall estimates which are of particular importance in areas with inadequate hydrometerological stations, such as within much of the HKH region.

In conclusion , there is a need to improve data collection, transmission, and modeling capabilities for timely flood forecasting. Sound research, combined with the use of state-of-the art technology, such as satellite-based products, are needed for an end-to-end reliable flood forecasting system with a better understanding of the end-users needs. Continued regional dialogue for transboundary cooperation and coordination to mitigate the adverse impact of transboundary floods will also be of critical importance.

Glacier Recession in Uzbekistan and its Consequences

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One of the most critical impacts of future recession and the disappearance of glaciers will incontestably occur in Uzbekistan. Here, the dry continental climate provides little annual rainfall and high evaporation rates at low altitude. The growing need for water is emphasized by urban centers' increasing demands on high-quality water for drinking and industrial purposes and rural regions' dependence on irrigation for production of primarily cotton. Also, hydroelectric power plants provide a significant contribution to secure local electricity supply.

Snow-glacial melt water is the main water source for mountain rivers in Uzbekistan during the summer period. Glaciers store water during the accumulation season (winter-spring) and release it during the ablation season (summer-autumn). This balance is primarily controlled by the amount of solid winter precipitation and summer temperatures. Increasing winter precipitation or decreasing summer temperatures lead to growing and advancing glaciers (positive glacier mass budget), whereas reduced winter precipitation or increasing summer temperatures result in diminishing and receding glaciers (negative glacier mass budget). The ability of glaciers to store water during the wet season and gradually release it during the dry season is vital to local agriculture and industry. If the glaciers disappear, snowmelt in the mountain ranges will feed rivers only during the spring and early summer, but then the rivers will dry out with devastating consequences for the population – such as drought, failed harvest, and famine – and for local ecology and ecosystems.

The situation in Uzbekistan and Central Asia is similar to the Himalayas, as there are no climatic reasons to assume otherwise. However, due to the dry climate in Uzbekistan, the consequences of climate change will be even more devastating for the local population.

The glacier deposits, located in the mountain areas of Central Asia, are the most important sources and longstanding reserve of clean fresh water. Producing melted water in the hottest time of the year, when the supply of seasonal snow is nearly exhausted, they compensate the deficit of irrigation water in times of the highest demand.

However the glacier deposits are not stable. At present, researchers-glaciologists observe all-round glacial recession: small glaciers are disappearing while large glaciers are degrading.

The mountains of Uzbekistan enter into the structure of Tyan-Shan and Alay mountain systems. On their territory turn the western spurs of Tyan-Shan and Gissar-Alay mountain system. Uzbekistan consists of 547 glaciers covering a total area of 231 square kms. The largest of them are Barkrak and Ayutor in Tashkent district. The Severtsev glacier in Kashkadarya region is also considerably large. The most critical rivers are Chirchik River (which supplies the capital of Tashkent and agricultural areas further downstream) and the upper Syr Darya River (which irrigates the fertile water-sensitive cotton-farming provinces of Andizhan, Namangan and Fergana). The Chirchik River irrigating Tashkent oasis is formed by the confluence of the rivers Chatkal and Pskem, whose headstreams are mountain glaciers of Pskem and Chatkal ridges. According to remote sensing and instrumental measurements, glaciers in Pskem region within the period from 1970 to 2001 have lost 29 % of their area.

At present, the process of glaciation shrinking continues. It is affirmed by field studies and multiple publications (Glazirin, 2003; Kotlyakov et al., 2006). In the course of degradation, the altitudes of glaciers ends by our calculations increased approximately from 40 to 100 meters (Toychiev et al., 2008). The retreating of glaciers leads to the shrinking of zones on which they make the cooling impact that leads to flora and fauna rearrangement of nival zone. In particular, during the period of the 2010 study (Tekeshsay river valley) it was noticed that the habitat of the Mensbir marmot has extended to an altitude of 2,200 m *asl*, where given species was not observed before. Glaciers of the river Pskem basin are presented with various forms of glaciation, which are transformed to each other in the course of degradation.

The process of degradation is widely presented by such forms of postglacial relief , as:

- Rock glaciers
- Thermokarst depressions
- Traces of small mudflows
- Formation of glacial lakes
  1. Small moraine dammed lake near Barkrak Middle Glacier
  2. Small ice-dammed lakes near Ozerniy glacier
  3. And big moraine-dammed Shavurkul Lake with 4 million cubic meter capacity
  4. In the Pskem valley also located two rock-dammed lakes: Ikhnach 1 and Ikhhach 2 with capacity 5 and 1 million cubic m correspondingly

The given lakes presents a potential threat of outburst to the densely populated valley of the river Pskem and further to the Charvak artificial lake (water reservoir accumulated water for Tashkent oasis).

Another big problem of glaciers recession is the problem of transboundary territories. According to remote sensing data interpretation of A. Yakovlev (aerial photos, analog space images, and Aster images) the glaciers of transboundary with Fergana valley basins, such as: Shakhimardan, Isfara, and Sokh have lost more than 18 % in area and 25 % in volume for the last 45 years. Many natural disasters, such as outburst of glacial lakes, earthquakes, floods are transboundary by the own nature. They can render direct and indirect influences on people's safety and living conditions. One examples is the flash flood which occurred in 1998 in Shahimardan Valley, when from the high-mountainous Archabashi Lake (Alay ridge, Kyrgystan), blocked by ice dam, resulted in an outburst of huge masses of water, which were discharged and carried away a large volume of stones and ice. The mudflow stream has fallen downwards, destroying houses, bridges, roads and other constructions and communications in Fergana valley and having done serious damage both to Kirghiz and to the Uzbek territories. This disaster in the Shahimardan valley took 100 human lives.

Conclusion

1. Most of glaciers on territory of Uzbekistan are in a state of degradation.
2. Glacial and rock dammed lakes in upstream of Tashkent oasis are potentially in danger of outburst.
3. One of the biggest problems of Uzbekistan, in addition to GLOFs, is the droughts.
4. The biggest potential hazard of GLOFs is concentrated on transboundary areas between Uzbekistan and Kyrgyzstan.

References

Mezencev V.S., Karnacevich I.V.,Humidity of Western – Siberian Plain. Leningrad: Gidrometioizdat; 1969, 168 pp.

Narama Ch., Kääb A., Duishonakunov M., Abdrakhmatov K. Spatial variability of recent glacier area changes in the Tien Shan Mountains, Central Asia, using Corona (~1970), Landsat

(~2000), and ALOS (~2007) satellite data. Global and Planetary Change (2009), doi:10.1016/j.gloplacha.2009.08.002

Toychiev Kh., Ni A., Tikhanovskaya A., Petrov M., Tomashevskaya I. Mountain glaciation, climate, runoff. Tashkent, Nation University of Uzbekistan after named M. Ulugbek, 2008. 85 p.

UNFPA (2007) Peering into the dawn of an urban millennium. UNFPA State of the World

Population, United Nations Population Fund (UNPF). http://www.unfpa.org/swp/2007

Volkova M., Tikhanovskaya A., Kharitonov G. Relation of the air temperature with glacier-geomorphological parameters of the Central Asia glaciers. Proceedings of SANII. Moscow: Gidrometioizdat; Issue 123(204). 1987. p.p. 72 - 80.

Yakovlev A., Batirov R. Monitoring of Mountain Glaciers and Glacial Lakes using ASTER Space Images. Proc. of the First International Conference on Hydrology and Water Resources in Asia Pacific Region (APHW 2003).-Kioto, Japan.- 2003.- Vol. 2, - 1042-1047 p.

The Peruvian Experience in the Treatment of Dangerous Lakes and the Expedition to Imja Lake and to the Valley Kumbhu in the Nepal Himalayas

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When we speak about the Himalayas we think of something very remote and mysterious, because the religious beliefs of the people of this area is very clear walking on the trails of these enormous valleys.

My first knowledge about the Himalayas was reading, in the late 1950s, about the great adventure of Mr. E. Hillary and Mr. Tenzing to conquer the summit of Mount Everest – the top of the world. The incredible force and decision of these people was a good example for future generations. How Hillary and Tenzing trained to reach the top of the mountain and their ensuing actions are testaments to their quality.

Thanks to Dr. Alton Byers, Dr. John Furlow, and the organizers of the expedition, the Peruvian team was invited to learn and enrich their knowledge and experience in these wonderful lands trekking in the high lands in a very detailed and patiently scheduled journey lasting more than three weeks.

We learned a lot from the people and the natural features of the Nepali mountains from the moment that we arrived at Kathmandu Airport. The familiarity with which we were received from the people of Kathmandu – thinking that we were locals – was a very friendly welcome, showing the commonalities we have in both our cultures as well as our ancestral origins.

We were invited to share with many other colleagues the modest but important experience we gained in Peru fighting against the forces of the nature since the late 1940s.

Since the disaster in Huaraz in December 1941, Peruvians started to analyze, make inventories, classify, and also began to carry out civil engineering works in the dangerous glacial lakes in order to reduce or avoid the destructive effects of the glacier hazards called GLOFs.

Now that we see the behavior and the development of this theme in other countries we could say that we are very proud of the work of the pioneers in Peru and also with our different governments, even though in some cases the decisions met with long delays to face this kind of natural hazard. The permanent support of the Peruvian government creating the Glaciology Office and giving the funds (sometimes very limited) allow us to carry on this important work that now continues with some limitations – but we have the hope and the concern to resume the high quality work that was shown mainly in the 1970s after the big earthquake that destroyed Ancash department and other neighboring regions. Peruvians, heirs of the strength and character of the Incas, started to work in the remote areas of the Cordillera Blanca in order to reduce the risk of the new growing glacier lakes and since the middle of the 1940s started to reduce the volume of the lakes and build structures to avoid the rise of the level of the waters and dams to counteract the effect of the waves produced by the ice avalanches.

The preliminary research and studies were carried out by geologists, civil engineers, and hydrologists at the very beginning and later, some people with basic glaciology knowledge came along. The basic parameters that have been defined were the volume of the lake, the main features of the geometry, and the structure of the natural dam, which means the moraines both lateral and terminal, the observed characteristics of the glacier, the distance and slope to the towns. The civil engineering projects were developed from that data and immediately executed.

Is important to mention that all this work has been made taking in to account and according the technical and economic resources of the country in order to maintain the correct technology scale.

The main parameters we measured, detected, and monitored were the amount or mass of hanging glacier, el slopes of the moraines both inside and outside, structure, geometry, materials and characteristics of the natural moraine, the amount of the outlet flow, and mainly, the volume of the lake.

The procedure in almost all the cases was to lower the level of the lake, reduce the volume, and then build a big duct capable of draining all the flows of the catchment area and avoid the rising again of the level of the water and finally, to restore the dam against the waves produced by the ice avalanches on the lake. At the beginning of the works in the 1950s and 1960s steel pipes were used for the ducts but in view of the acid waters, we changed to reinforced concrete

The way to lower the level of the lakes has been digging open cuts when the moraine has loose material and tunnels when the natural dam was rocky. In this last case, generally we left at least 15 meters of free board and in other cases also 20 meters as in loose material dams. The restored dams have been well compacted earth dams according to the specifications of the regular soil mechanics with the required compacting equipment and waterproofed with a coverage of rocks whose joints are sealed with cement mortar.

That is the way we worked in 35 lakes but with the recent global warming and the consequent accelerated glacier retreat the size of the lakes has increased and become more dangerous, so we have had to redesign the projects and enlarge the pipes and the dams.

Since the 1960s, we also started the glaciology research measuring the mass balance, front glacier variation, etc.

The Imja Lake

The main target In this expedition was to reach the Imja Lake to see its conditions and the magnitude of the hazard that has been identified some time ago.

It was very clear from the beginning that the structures of the moraine, the volume of the lake, the presence of ice close or perhaps inside to the terminal moraine makes this lake considered dangerous. The unknown current conditions of the terminal moraine and the ice despite the research made some years ago have some unknowns than have to be clarified in order to adopt appropriate criteria or actions.

However, if the situation becomes difficult because of the concerns of the people living downstream the valley, it is possible to design a siphon system which could start to drain the lake and lower its level. To do this, it is necessary to know the amount of the outlet flow because the pipe flow has to be larger than the current outlet flow but at the same time, after reducing the level of the lake, it would be important to start to make open cuts in to the dry moraine above the new level of the lake.

The order of the actions has to be always begin with studies and research to know with a good degree of certainty the conditions of the moraine and the nearby ice.

Personally, I believe one important thing to know is if the lake is dammed mainly by the ice or the moraine because the poor quality of the moraine material and its weak conditions leave serious doubts about its behavior under the direct hydrostatic water pressure of the lake given the poor consolidated loose material. In this sense, I think that if the surrounding ice breaks suddenly and all the hydrostatic pressure is against the moraine it could fail and collapse very quickly through a piping process by the same body of the moraine or regressive erosion by an increase of the flow over the outlet.

Anyway, we are very concerned about this lake and its poor conditions of stability. In order to take actions soon to avoid possible catastrophic consequences, it will be important to know as soon as possible the above-mentioned basic parameters and make a very detailed plan and schedule works as follows:

1. Studies and research of the basic parameters to take a decision.
2. Parallel search of some options taking in to account siphoning, open cut immediately after the siphoning, construction of the duct (reinforced concrete), restore the dam.
3. One very important issue to take into account is the kind of logistics during the studies and the possible civil engineering works.
4. If the studies and the research show that there is some kind of emergency, transport only with people (sherpas) would not be advisable – use helicopters.

Everything that has been written above is from the point of view of the hazard and its treatment from the physical science background, but from the side of the financing organizations there is a big question about the vulnerability and the amount of the risk that this lake represents from different angles. This means that at the same time of the physical analysis of the problem, it will be very important for the real justification of the project to evaluate the vulnerabilities – social, physical (infrastructure), economical (tourism), production (agriculture), cultural, etc.

On the one hand, we already know something about the physical conditions; in addition to knowing the magnitude of the vulnerability we could assess or evaluate the magnitude of the risk and then show the justification of the investment.

From my very personal point of view I think that humanity wants to preserve this valley below Imja Lake and others surrounding Mount Everest because of the great value of this human heritage for all the people who come to this area from around the world to see the top of the earth; they are interested in preserving this beautiful area for the future, because as we saw, the principal activity for three or four months of the year is tourism.

The Peruvian team is committed to help in this objective with its modest technical collaboration and will always be ready to give ideas for studies, the project, and, if decided, to collaborate in future works.

We know for sure that the various people involved in this common purpose will do their best to carry out the best studies and research, to make the best decisions, and execute the needed actions to reach the goal and main objectives of the organizers of the expedition, of the people who live in the area, and more generally, for the Nepali people and humankind in general.

In closing, we should say that we are very grateful to the organizers of this expedition – all of them. We could not avoid mentioning Alton Byers and John Furlow for their invaluable support, without which it would not have been possible to enjoy this fantastic experience.

Social-ecological Pastoralist System's Responses to Socioeconomic, Political, and Climatic Changes in Carabaya (Puno, Peru)

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Introduction

Human-driven transformation of the biosphere is threatening Earth's life-support systems, creating an urgent need for a theoretical framework to understand sustainability of social-ecological systems (SESs) (*1-4*). Several schemes for analyzing site-specific SES have been proposed (*5-7*) that aim to advance the understanding of sustainability and resilience. This paper contributes the case of a pastoralism SES in the high Andes of Peru. It also shows how distant drivers and proximate causes engender local changes in an SES.

The case

The Quelcaya SES is composed of the pastoralist society and the *Puna* ecosystem, which are linked through pastoralism. Thus, it is pastoralism, as a social activity, that creates this high Andean SES. Over centuries, this SES has self-organized and has been resilient to changing social and environmental settings. However, recent multi-scale social and environmental changes are disturbing the Quelcaya SES, challenging its resilience and jeopardizing its sustainability. Though successful responses portray the adaptive governance paradigm, this case also requires i) poverty alleviation and improved living conditions, ii) synergies amongst the elements of dynamic resilience and adaptive capacity, and iii) transformability of the institutional framework of natural resource use. The interactions between global and local processes are asymmetric because the influence often operates from global to local and seldom otherwise. This paper follows this pattern flowing from a discussion of the general and global arena to down to the local Quelcaya SES, wherein the dynamic impacts and responses are shown.

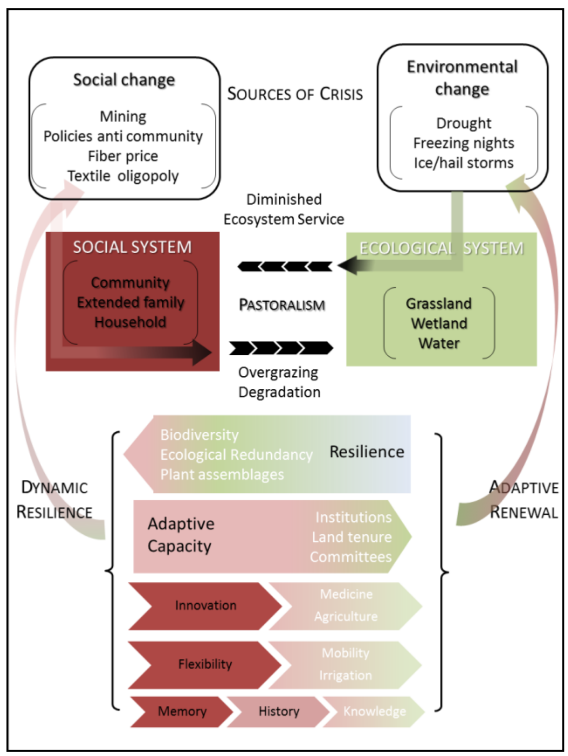

Figure 1. Quelcaya Social-Ecological System

In the case of the Quelcaya SES (Figure 1), the main variables of the social setting that affect local livelihoods are fourfold: 1) national policies, 2) mining, 3) fiber prices and the oligopoly of the textile industry, and 4) poor basic services. The variables of the environmental setting (Figure 1) are changes in precipitation and temperature, glacier retreat, drought, freezing nights, and ice/hail storms, all of which have become more intense and frequent under climate change (*8-10*), diminishing ecosystem services (for the Andes see: *11, 12*), thus jeopardizing the SES's sustainability.

Responses to changes in the Quelcaya SES

The Quelcaya pastoralists have lived in their territory for over 130 years (*13*). During these years they have defended their lands from surrounding landowners and other communities that have attempted to access and control Quelcaya's pastures. In so doing, the Quelcaya community has taken advantage of legal and administrative opportunities – e.g., norms that protected communities' land rights – resisted or, opportunistically, used government initiatives. Further, pastoralism is the main livelihood in Quelcaya and because of that, pastoralists and the landscape have changed and been changed by each other. In this mutual interaction, Quelcaya illustrates that dynamic resilience and adaptive renewal operate across several time spans, thereby creating a sustainable SES.

Environmental change characterizes life in mountains. Ecosystem resilience and adaptive renewal have three major interweaving subunits: biodiversity, ecological redundancy, and plant assemblages (*14-16*). These subunits characterized the forelands of the Quelcaya ice cap, as follows. Fifty-two plant species were found in the area ranging from 4,829 to 5,113 m – encompassing an area from the wetlands up until the lower border of four glacier edges of the Quelcaya ice cap. Along the altitudinal gradient, there are four plant assemblages. The species' upper limit is moving upwards, while species richness is skewed toward the lower half of altitude gradient. Low beta-diversity in the glacier outlets shows a trend towards vegetation homogenization with time (as was found in the Alps by *17*).

Social system resilience is due to its adaptive capacity, innovation, flexibility, and creative memory (*18-20*). The adaptive capacity of the Quelcaya social system is expressed through its institutional flexibility, which is illustrated by observing the changing institutional arrangements throughout their history. An example of institutional changes in Quelcaya is the formation of committees to undertake specific tasks, which not only illustrates the use of institutions and organizations as a means to address issues or distribute responsibilities, but also is evidence of Quelcaya's institutional dynamism and vitality. In the past 20 years, the community has created an array of committees to undertake activities, including vicuña shearing, communal house building, and the night-guard committee (ronda), originally created as communal protection against livestock rustling (for a description of Peruvian rondas see *21, 22*).

Quelcaya's social system has been resilient through strategies that combine traditional ecological knowledge, use of multiple pastures, and dynamic social organization. The backdrop of these strategies is a cultural flexibility to incorporate innovations, which in turn redefine peoples' social memory to keep history present (*23*). For instance, mobility has been a paramount characteristic of pastoralism, and the seasonal grazing strategy aims to prevent overgrazing and degradation; it has also been a mechanism to cope with pastures covered by snow/hail or frozen, and to avoid having animals rest on areas with poor drainage. Further, in addition to livestock mobility, herders have been incorporating veterinarian knowledge such as giving medicine – e.g., antibiotics and vitamins – to the livestock to improve their health and ability to cope with harsh climatic conditions. Some elements of technical herding have been incorporated as well, to improve fiber quality and yield. Quelcaya's pastoralists are responding to droughts by enlarging and creating wetlands by irrigating pastures through dirt channels that are rebuilt each year depending on the location of the water source and of the pasture. Some of these channels are several kilometers long; building them requires cooperation and organization for the work. Appropriate social institutions are needed.

Pastoralists have diversified their herds, forming a mixed flock of alpaca, llama, and sheep. This alleviates pressure on the pasture because each one of these species prefers different plants and areas to graze (*24-26*). Further, this diversification diminishes the vulnerability of depending on only one animal species for sustenance. Llama and sheep have different functions – the former is a beast of burden, and the latter provides wool, meat, and serves as a living savings account. Llamas allow the household to undertake long-distance caravans to barter pastoralists' products for maize and potatoes. Though challenged by the development of new networks of roads, caravans are a key element in household economy. Caravans provide mobility and choice in markets for selling or bartering products, thereby sheltering households from price dynamics and uneven terms of trade (*27-29*). Further, bartering provides a better rate than cash sale, while it occurs amidst an institutional framework crafted by ceremonial kinship relations and long-standing barter exchanges (*30*).

Concluding remarks towards sustainability

Poverty and marginalization hamper the adaptation of any human group, more so in the case of a group of exclusive pastoralists – i.e., without agriculture – living above 4,000 m under harsh climatic conditions. Improving public services such as education and health with infrastructure, equipment, and professionals would enhance local human capital. Housing conditions need to be improved through a government (or NGO) program which will provide better health conditions and lower the incidence of respiratory diseases.

Global drivers of change like climate and economic forces, acting locally, are pushing systems' resilience worldwide, and possibly leading some systems to new states (*7, 18, 31, 32*). In so doing, it fosters clashes of land uses and of the human-environment relations that support them (*33*). It also increases the tensions and competition amongst users (*5*). Government, economic forces, and local populations have views and agendas about the SES that are almost fully incompatible, thereby raising issues in the political and political economy arenas, as well as in the institutional framework for natural resource governance (*34, 35*).

Synergies between gradual and abrupt change are challenging the Quelcaya SES. Changes are driven not only by underlying and proximate social, political, and ecological processes but also by legacies – events from the past that influence actual SES dynamics (*36*). Further, herder activities, which depend on legacies and goals for the future, are shaped and will continue to be shaped by change. These interactions may lead to uncertain system dynamics. This uncertainty includes regime shifts if the system is unable to adapt; however, research is needed to assess the thresholds of the system. Droughts and cold spells are expected to be more frequent, last longer, and have greater intensity, whereas Quelcaya's SES resilience has been diminished by exogenous and endogenous human action. Following Chapin and colleagues (*7*), a suit of multi-scale policy strategies are suggested to enhance the dynamic resilience and adaptive capacity of the Quelcaya SES. Further, linking scientific knowledge with local knowledge will increase understanding of ongoing processes of change and the likelihood of developing adaptive strategies. The linkage of knowledge and policy would require that the government regain its role of promoting rural development, restating agrarian extension, and technical diffusion of opportunities derived from change. For instance, local responses – e.g., irrigation of pastures and wetlands – that have proven to be effective stabilizing feedback mechanisms may be replicated by programs of the regional governments. Regional authorities and non-governmental organizations (NGOs) should provide financial and technical support in building small- to medium-scale reservoirs and water storage systems for the dry season. Fodder production is critical to sustaining livestock; thus, applied research to develop cultivated grass and irrigation systems, as well an investment in silos to ensile grass will enhance the resilience of the productive system. Diversifying the livestock production to meat and hide products will diminish dependency on fiber. Further, NGOs and local authorities could train pastoralists to undertake these new activities following technical standards, while the regional and local governments could promote high Andean products such alpaca meat in urban markets.

A potential trajectory towards a sustainable Quelcaya SES may be a better science-policy interface through bridging organizations (*37*). Despite the absence of such organizations for Quelcaya, scientific teams have been a long-term presence understanding climate change through glacier dynamics in the largest tropical glacier of the world since early 1960s (*38-41*). It may be the case that scientists and science need to be more flexible, expand and adapt their roles to times of critical change, walking – more often – beyond the ivory tower and bridging to policy makers and stakeholders with the goal of creating a sustainable and equitable multi-scale world. The project *Adapting to a Changing Mountain World* is an example of linking local knowledge and science of Peru to tackle the effects of global change in Nepal. The outcome of this collaboration may foster stakeholders' involvement in dialogue and debate towards sustainable development in the Global South.

References Cited

1. E. Ostrom, *Science* 325, 419 (July 24, 2009, 2009).

2. W. C. Clark, N. M. Dickson, *Proceedings of the National Academy of Sciences of the United States of America* 100, 8059 (July 8, 2003, 2003).

3. B. L. Turner, E. F. Lambin, A. Reenberg, *Proceedings of the National Academy of Sciences* 104, 20666 (December 26, 2007, 2007).

4. O. R. Young *et al.*, *Global Environmental Change* 16, 304 (2006).

5. R. R. Rindfuss, S. J. Walsh, B. L. Turner II, J. Fox, V. Mishra, *Proceedings of the National Academy of Sciences of the United States of America* 101, 13976 (September 28, 2004, 2004).

6. F. Berkes, J. Colding, C. Folke, *Navigating social-ecological systems : building resilience for complexity and change* (Cambridge University Press, Cambridge, U.K. ; New York, 2003), pp. xxi, 393 p.

7. F. S. Chapin *et al.*, *Proceedings of the National Academy of Sciences* 103, 16637 (November 7, 2006, 2006).

8. FAO, Y. Fernández de Larrinoa Arcal, Ed. (FAO, 2008).

9. C. Valdivia *et al.*, *Annals of the Association of American Geographers* 100, 818 (2010).

10. A. Seth, J. Thibeault, M. Garcia, C. Valdivia, *Annals of the Association of American Geographers* 100, 835 (2010).

11. M. Quintero, in *Servicios ambientales hidrológicos en la región Andina. Estado del conocimiento, la acción y la política para asegurar su provisión mediante esquemas de pago por servicios ambientales* M. Quintero, Ed. (IEP/ CONDESAN, Lima, 2010) pp. 193-226.

12. E. P. Anderson *et al.*, in *Climate change and biodiversity in the tropical Andes* S. K. Herzog, R. Martínez, P. M. Jorgensen, H. Tiessen, Eds. (Inter-American Institute for Global Change Research (IAI) and Scientific Committee on Problems of the environment (SCOPE), 2011) pp. 1-18.

13. Fondo Tesorería Fiscal, in *Fondo Tesorería Fiscal. Padroncillos. Libro 725*. (Puno, 1863).

14. D. U. Hooper *et al.*, *Ecological Monographs* 75, 3 (2005).

15. M. Loreau *et al.*, *Science* 294, 804 (2001).

16. T. Elmqvist *et al.*, *Frontiers in Ecology and the Environment* 1, 488 (2003).

17. G. Jurasinski, J. Kreyling, *Journal of Vegetation Science* 18, 711 (October 01, 2007, 2007).

18. C. Folke, J. Colding, F. Berkes, in *Navigating social-ecological systems : building resilience for complexity and change* F. Berkes, J. Colding, C. Folke, Eds. (Cambridge University Press, Cambridge, U.K. ; New York, 2003) pp. 352-387.

19. C. Holling, L. Gunderson, in *Panarchy: Understanding Transformations in Human and Natural Systems* L. Gunderson, C. Holling, Eds. (Island Press, Washington, 2002) pp. 25-62.

20. D. R. Nelson, W. N. Adger, K. Brown, *Annual Review of Environment and Resources* 32, 395 (2007).

21. O. Starn, *Nightwatch: the politics of protest in the Andes* (Duke University Press Books, 1999), pp.

22. G. Nuñez Palomino, *Journal of Legal Pluralism* 36, 111 (1996).

23. R. J. McIntosh, in *The way the wind blows: climate, history, and human action* R. J. McIntosh, J. A. Tainter, S. K. McIntosh, Eds. (Columbia Univ Pr, New York, 2000) pp. 141-180.

24. B. McGregor, *Small Ruminant Research* 44, 219 (2002).

25. F. C. Bryant, A. Florez, J. Pfister, *Journal of Animal Science* 67, 3087 (1989).

26. J. A. Pfister *et al.*, *Applied Animal Behaviour Science* 23, 237 (1989).

27. X. Ricard Lanata, G. Valdivia Corrales, *Tejedores de espacio en los Andes. Itinerarios agropastoriles e integración regional en el sur peruano* (Centro de Estudios Regionales Andino Bartolomé de las Casas / Grupo Voluntariado Civil de Italia, Cuzco, 2009), pp. 128.

28. N. Tripcevich, in *Trade and Exchange* C. D. Dillian, C. L. White, Eds. (Springer New York, 2010) pp. 59-73.

29. T. Inamura, in *Etnografía e historia del mundo andino: Continuidad y cambio* S. Masuda, Ed. (Universidad de Tokio, Tokio, 1986) pp. 141-190.

30. B. S. Orlove, *Current Anthropology* 27, 85 (1986).

31. E. F. Lambin, H. J. Geist, E. Lepers, *Annual Review of Environment & Resources* 28, 205 (2003).

32. L. Gunderson, C. Holling, *Panarchy: Understanding Transformations in Human and Natural Systems* (Island Press, Washington, 2002), pp. 507.

33. E. F. Lambin, P. Meyfroidt, *Proceedings of the National Academy of Sciences* 108, 3465 (March 1, 2011, 2011).

34. A. J. Bebbington, J. T. Bury, *Proceedings of the National Academy of Sciences* 106, 17296 (October 13, 2009, 2009).

35. C. Holling, L. Gunderson, D. Ludwigh, in *Panarchy: Understanding Transformations in Human and Natural Systems* L. Gunderson, C. Holling, Eds. (Island Press, Washington, 2002) pp. 3-22.

36. F. S. Chapin III, C. Folke, G. P. Kofinas, in *Principles of ecosystem stewardship: resilience-based natural resource management in a changing world* F. S. Chapin III, G. P. Kofinas, C. Folke, Eds. (Springer Verlag, New York, NY, 2009) pp. 3-28.

37. L. H. Gunderson, C. Holling, S. S. Light, *Barriers and bridges to the renewal of ecosystems and institutions* (Columbia Univ Pr, 1995), pp.

38. L. G. Thompson, S. Hastenrath, B. Morales Arnao, *Science* 203, 1240 (1979).

39. B. G. Mark, G. O. Seltzer, D. T. Rodbell, A. Y. Goodman, *Quaternary Research* 57, 287 (May, 2002).

40. L. G. Thompson *et al.*, *Proceedings of the National Academy of Sciences of the United States* 103, 10536 (July 11, 2006, 2006).

41. L. G. Thompson, E. Mosley-Thompson, B. Morales Arnao, *Science* 226, 50 (1984).

Reconstruction of Quaternary Glaciation in Tien-Shan and Pamir from New Starting Positions

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[Editor's Note: In this section, Dr. Shatravin provides three different papers dealing with high mountain environments and processes in the Tien-Shan and Pamir mountains of Kyrgyzstan, plus a list of recommendations for further study of Imja Lake]

Using the Tien-Shan and Pamir as examples, it is demonstrated that the root cause of problems and contradictions in reconstruction of the Quaternary glaciation and stratigraphic segmentation of the Quaternary alpine deposits is fallacy in traditional genetic typification of true moraines and pseudo-moraines. The absence of reliable absolute ages of moraines aggravates the problem. One can make a conclusion that all of these factors together have brought the researchers to a deadlock. Based on the author's own quantitative genetic and correlation criteria of Quaternary alpine deposits and the methodology of direct C-14 dating of moraines (on autochthonous organics), a scheme of Pleistocene and Holocene glaciation segmentation was developed for the North Tien-Shan; further, it was demonstrated that there was only one Pleistocene glaciation in the Tien-Shan and Pamir mountains

Researchers have been doing paleoglacial reconstructions of the Quaternary for over 100 years. However, they have not definitely established even the number of Pleistocene glaciations on Earth, and have not clarified the very nature of Holocene glaciation. Tien-Shan and Pamir are not exception in this regard. The existing paleoglacial information for these regions is fragmentary and quite contradictory. In general, this subject is a big informative mess.

The author's previous works have demonstrated that main cause of those contradictions, i.e. *incorrect* (erroneous) initial positions of the researchers: for segmentation of the Quaternary, they used both true moraines and pseudo-moraines as climatic-stratigraphic benchmarks. Based on the author's quantitative facial-lithological indicators (geochemical, granulometric and others) tested in Tien-Shan, Pamir and partly in Caucasus, it was established that all morpho-lithologic formations of high-mountainous areas that have traditionally taken for other researchers as Early-and Middle Pleistocene moraines, as well as significant of such formations taken as Late Pleistocene moraines in fact Holocene (rather Late Pleistocene – Holocene) pseudo-moraines (in composite stratigraphic section they occupy a position between the Late Pleistocene and Holocene moraines), the true genesis of which no glacial but gravitational and they are presented by widely developed specific landslides [1, 2, 3].

This discovery allowed to reveal the very «root of all evils» that prevents to make correct paleoglacial reconstructions and stratigraphic segmentation of the Quaternary in the Alpine regions.

It was demonstrated that glacial lithogenesis with formation of moraines takes place in the so-called geochemical facies of ferrous iron, while gravitational lithogenesis with formation of pseudo-moraines takes place in geochemical facies of ferric iron. In this context, the most representative and quite adequate genetic property of true moraines and pseudo-moraines is iron oxide/protoxide ratio (Fe_2O_3/FeO). A good addition to it are granulometric indicators, including clay content.

The other important reason is the absence of trustworthy absolute datings of moraines. All the available C-14 data for these regions had been obtained exclusively on allochthonous organic, therefore they are not reliable and often misguiding. TL-dating have been tried on sediments of glacial and interglacial epochs in Pamir [4]. However, this exercise should be considered as a failure for the following reasons:

1. the very method of TL-dating is at the development stage, and it is developed exclusively for loess deposits;
2. according to interlaboratory control tests, the margin of error of this method comes up to 300-400% [5];
3. besides scattered datings, there is significant overestimation of ages compared to C-14 datings, and the older is the age of sediments the higher gets this overestimation (TL-dating of the Caspian lake sediments produced ages over 10 (!) times higher than C-14 ages) [6].

Therefore, the use of such dates is only producing more mess in this subject. In general, paleoglaciology and Quaternary geology now find themselves without reliable climate-stratigraphic benchmarks, which makes further research in this field hopeless.

The author has developed a reliable method of C-14 dating of moraines using the dispersed glacial organic matter, which is autochthonous and syngenetic to the moraines [1, 7]. This method was refined during the ISTC project #Kr-330.2, and it has already received the world's first direct (i.e. based on autochthonous organics) radiocarbon ages of Holocene moraines [8]. This way, geochronologic veil was removed from moraines, the major climate-stratigraphic benchmarks of the Quaternary.

Competent genetic typification of moraines and pseudo-moraines and the method of direct C-14 dating of moraines together make the new starting positions in paleoglaciology and Quaternary Geology.

The resulting facial-lithological data present strict correlative and paleoclimatic criteria.

It has been found that during the genetic transformation of moraine and pseudo-moraine deposits into alluvial/proluvial deposits, the oxide/protoxide ratio and clay content of the original deposits are well preserved. To make this point more clear, a scheme of such correlation is given in the Fig. 1.

One must note that in the Tien-Shan and Pamir, the alluvial/proluvial deposits of the Early and Middle Pleistocene show extremely high values of oxide/protoxide ratio, i.e. they belong to the geochemical facies of ferric iron.

The use of these criteria allowed to establish definitely that there was only one Pleistocene glaciation in the Tien-Shan and Pamir, and it occurred in the late Pleistocene [9, 10].

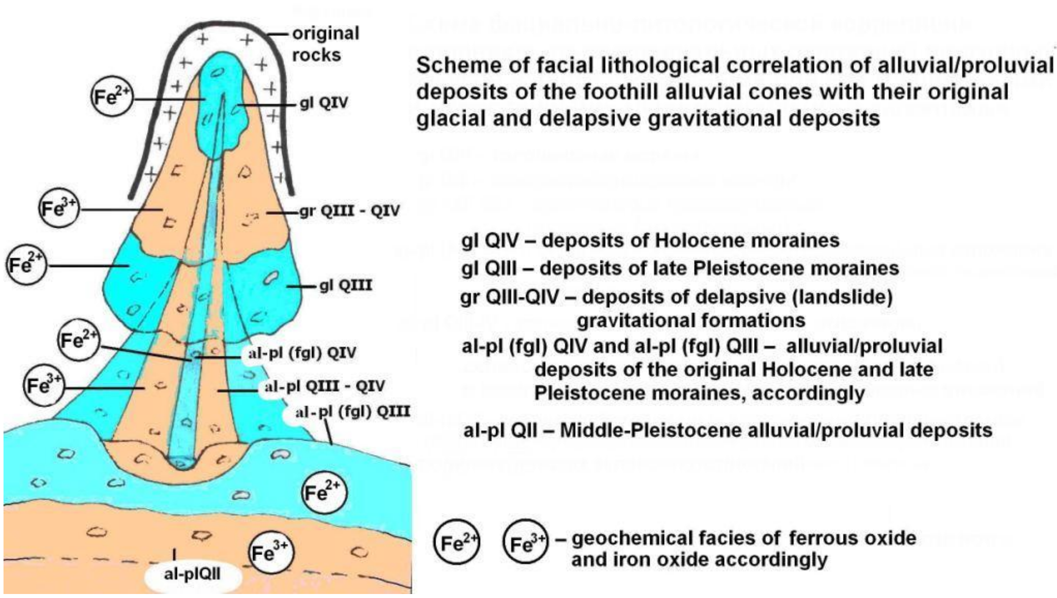


Fig. 1. Scheme of facial lithological correlation of alluvial/proluvial deposits of the foothill alluvial cones with their original glacial and delapsive gravitational deposits.

gl QIV – deposits of Holocene moraines; gl QIII – deposits of late Pleistocene moraines; gr QIII-QIV – deposits of delapsive (landslide) gravitational deposits; pl (fgl) QIV and pl (fgl) QIII – alluvial/proluvial deposits of the original Holocene and late Pleistocene moraines, accordingly ; (Fe/2+) and (Fe/3+) – geochemical facies of ferrous and ferric iron, accordingly. Note: alluvial/proluvial deposits formed during direct redeposition of glacial deposits can be called fluvioglacial, which is reflected in a special symbol for them – pl(fgl).

Under the above mentioned project, paleoglacial schemes of Late Pleistocene and Holocene segmentation have been composed from the new starting positions on the North Tien-Shan material [9]. These schemes show that the late-Pleistocene glaciation occurred in three stages, and the deglaciation took place in a decrementing manner. This last (third) stage was the smallest one. The correlation of paleoglaciation with paleo-levels of closed mountainous lakes of Chatyr-Kul (Tien-Shan) and Kara-Kul (Pamir) performed with the use of C-14 datings and pollen data allowed to establish that the maximum of the last stage of the Late Pleistocene glaciation took place about 30,000 years before present, and the complete deglaciation of this stage (hence, of all Late Pleistocene glaciation) occurred about 23,000 years before present (ybp). The Holocene glaciation in Tien-Shan started in the early Holocene, and the maximum of the first stage took place 8,000 ybp.

The period between 23,000 and 8,000 ybp was glaciation-free, associated with massive gravitational lithogenesis (demonstrated itself in form of natural cataclysms) with formation of pseudo-moraines. Such pseudo-moraines as opposite to true moraines are distinct paleoclimatic benchmarks of a warm and humid period.

The Holocene glaciation was also decomposing in a staged and decrementing manner. There were found at least 7 stages, decreasing in size and duration. This scheme is shown in the Fig. 2.

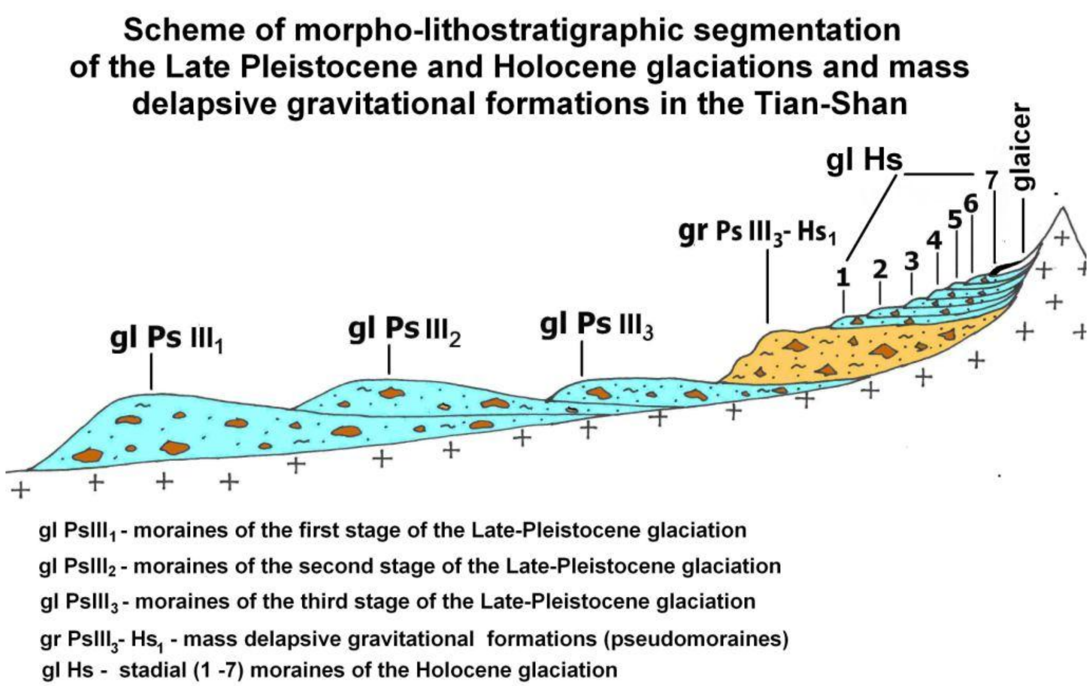


Fig. 2. Conceptual scheme of morpho-lithostratigraphic segmentation of generations of late Pleistocene and Holocene glaciations and massive delapsive gravitational formations in the Tien-Shan.
The intervals between the maximums of Late Pleistocene glaciation stages and the interval between the last stage of late Pleistocene glaciation and the Holocene glaciation 20-22 thousand years. All this allows to make the following preliminary conclusions:

- Disintegration of Pleistocene glaciation in Tien-Shan took place in a stage-by stage (possibly, harmonious) and decrementing manner;

- The Holocene glaciation can be considered as just a regular stage of the disintegrating Pleistocene glaciation.

From the application of the new starting positions in Pamir, obvious tracks of the Late Pleistocene glaciation in form of moraines were found only in the East Pamir and in a small area of the Central and North Pamir, in the area of development of Fedchenko paleo-glacier [10]. In the West and South Pamir, the existence of Late Pleistocene moraines (and glaciation as such) is still to be confirmed.

The traditional glacial models of segmentation of the Quaternary and paleoglacial schemes have long been recognized as not viable.

Paleoglaciology, as well as Quaternary geology must be "pulled out" of the deadlock, rather than waiting till after many decades, or even centuries, "the quantity will transform into quality." People need a reliable long-term forecast of glaciation and climate today and this problem becomes more and more urgent.

Changing the situation and getting necessary results quite soon can be achieved in only one manner: taking the new starting positions and performing paleoglacial studies on a new level (based only on quantitative facial-lithological indicators and direct absolute datings).

Literature

1. Shatravin V.I. *Fatsialno-litologicheskie osobennosti chetvertichnykh otlozheny vysokogornykh zon Severnogo Tyan-Shanya* (Facial-lithologic features of quaternary deposits of high mountainous areas of the Northern Tien-Shan). Summary of the thesis for the degree of candidate of geology and mineralogy. Institute of Geology of the Academy of Science of the Kyrgyz Republic. Bishkek, 1992. 21 pp.
2. Shatravin V.I. *Fatsialno-litologicheskaya tipizatsia osnovnykh geneticheskikh generatsy chetvertichnykh otlozheny vysokogornykh zon* (Facial-lithological typification of the main genetic generations of the Quaternary sediments of high-mountainous zones) // *Geologia kaynozoya i seysmotektonika Tyan-Shanya* (Geology of the Cenozoic and seismotectonics of Tien-Shan) Bishkek, "Ilim", 1994a, -pp. 3-15.
3. Shatravin V.I. *Osnovnye zakonomernosti glyatsialnogo i gravitatsionnogo tipov litogeneza gornykh rayonov* (The basic principles of glacial and gravitational types of lithogenesis of mountainous areas). // *Geologia kaynozoya i seysmotektonika Tyan-Shanya* (Geology of the Cenozoic and seismotectonics of Tien-Shan). Bishkek, "Ilim", 1994b,- pp. 15-26
4. Vlasov V.K., Kulikov O.A., Nikonov.A.A. *Pervye dannye o vozraste lednikovyh kompleksov Pamira po dannym RTL – analiza* (The first data on age of glacier complexes in Pamir according to RTL-analysis) // Reports of the Academy of Science of the USSR, 1984. vol. 279, 36.
5. Shlyukov A. I., Voskovskaya L.T., Lyaschenko M.G. (Faculty of Geology, Moscow State University); Shahovets S.A. (TIG DVO AN USSR, Vladivostok); Sheikman V.S. (Tallinn State University). *Progress novoi TL tehnologii na Russkoi ravnine.* (The Progress of new TL technology on the Russian Plains)// in: *Materialy Vsesoyuznogo soveschaniya po geohronologii chetvertichnogo perioda.* (Materials of All-Union Consultations on the Quaternary Geochronology). Moscow, 1990.
6. Kaplin P.A., Leont'ev O.K., Rychagov G.I. et al. *Hronologiya i paleogeografiya pleistotsena Ponto-Kaspiya (po dannym absolyutnogo datirovaniya).* (Chronology and Paleogeography of Pleistocene in Ponto-Caspian (according to results of absolute dating) *//* in: *Paleogeografiya i otlozheniya pleistotsena yuzhnyh morei SSSR* (Paleogeography and Sediments of Pleistocene in South Seas of the USSR). Moscow, «Nauka», 1977. – pp. 33-68.
7. Shatravin V. I. *Radiouglerodnoe datirovanie «nemyh» tolsch chetvertichnyh otlozhenii.* (Radiocarbon dating of "dumb" layers of the Quaternary sediments) *//* in: *Glavneishie itogi v izuchenii chetvertichnogo perioda i osnovnye napravleniya issledovanii v XXI veke* (The Main Results in the Studies of the Quaternary and the Main Directions of Studies in the 21st Century). (Abstract of presentation to the All-Union Consultations) VSEGEI. Saint Petersburg, 1998. – p. 55.
8. Shatravin V. I. *Radiouglerodnoe datirovanie moren po rasseyannoi organike.* (Radiocarbon dating of moraines on dispersed organics) *// Klimat, oledenenie, ozera Tyan-Shanya: puteshestvie v proshloe* (Climate, Glaciation, Lakes of Tien-Shan: Journey to the Past). Bishkek: "Ilim". 2007. pp. 74-92.

9. Shatravin V. I. *Rekonstruktsiya pleistotsenovogo i golotsenovogo oledenenii Tyan'-Shanya s novyh ishodnyh pozitsii* (Reconstruction of Pleistocene and Holocene glaciation in Tien-Shan from new starting positions) // *Klimat, oledenenie, ozera Tyan-Shanya: puteshestvie v proshloe* (Climate, Glaciation, Lakes of Tien-Shan: Journey to the Past). Bishkek: "Ilim". 2007. pp. 26-46.

10. Shatravin V. I . Reconstruction of Pleistocene and Holocene glaciations in Tien-Shan and Pamir: New Results // Pamir and Tien-Shan: Glacier and Climate Fluctuations during the Pleistocene and Holocene. International Workshop, July 22-23, 2000. Institute of Soil Science and Soil Geography, Univ. of Bayreuth, Germany

Establishment of regularity of disintegration of the Holocene glaciation through radiocarbon dating of dispersed organic matter from moraines

In the Holocene moraine-glacier complexes of the Tien-Shan, there was found a distinct morphological regularity that confirms the stadial nature of Holocene deglaciation. in those complexes, one can distinctly identify at least 7-8 major sequential terminal morainic bars correlating with the Holocene glaciation stages. For the first three of those bars, radiocarbon ages have been established on the dispersed organic matter, which is autochthonous and syngenetic to the moraines. On this basis, there was developed a conceptual scheme of Holocene deglaciation in the Tien-Shan, which can be used as a working model for long-term prognosis of natural glacial and climate changes in Central Asia.

Paleoglacial reconstructions are based on absolute dating of moraines.

Moraines are *traditionally* considered as chronologically "dumb" formations due to absence of autochthonous organics necessary for radiocarbon dating. Previously, the author has found in moraines autochthonous and syngenetic with moraines to receive its nature was established and a possibility to use these organics for radiocarbon dating of moraines demonstrated [1, 2]. Methodology of the field and laboratory works for preparation of morainic samples for radiocarbon analysis has been elaborated [3]. In general, this methodology represents a new, non-traditional method of radiocarbon dating of moraines.

Under the project ISTC #Kr-330.2, three radiocarbon datings of Holocene moraines have been received on these organics; they should be recognized as the world first of its kind, i.e. on autochthonous organics. Radiocarbon analyses have been done in parallel in two independent laboratories: the Laboratory of geochronology at the University of Saint Petersburg (Russia) on the traditional radiometric equipment, and in the Vienna Atomic Institute (Austria) with the use of AMS technique. The results demonstrated good convergence. This allows to recognize the C-14 method of dating moraines on dispersed organics as viable. This way, the geochronologic «veil» was taken off moraines.

For radiocarbon dating of Holocene moraines and associated paleoglacial reconstructions, the most suitable were moraines of small glaciers, mainly of cirque glaciers. Small glaciers are situated far from the centers of glaciation of mountain ranges, therefore they demonstrate the most sensitive reaction to climate changes, imprinting such changes in the form of (stadial) moraines of recession. For the first three stadial moraines of one Holocene moraine-glacial complex in Tien-Shan, the following radiocarbon dates have been received: 8000, 5000 and 3400 years [3, 4]. There are at least 7-8 such morphologically well-articulated stadial moraine lines of Holocene glaciation in Tien-Shan. Their exact number, as well as the number of smaller moraine lines is yet to be established (Fig.1).

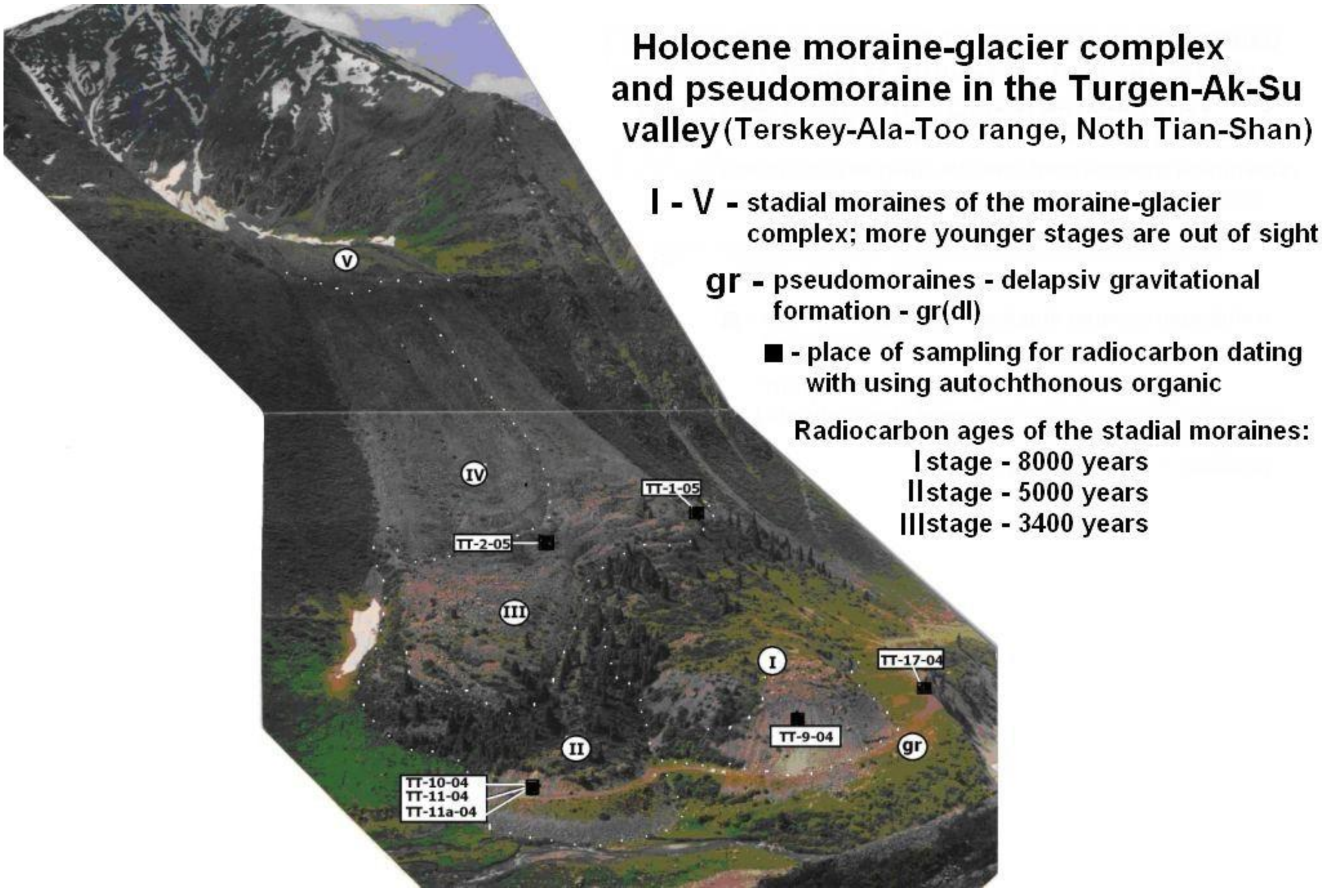


Fig. 1. Morphologically expressed staged moraines (I-V) in the Turgen-Ak-Su moraine-glacier complex (basin of Turgen-Ak-Su river, Northern Tien-Shan)

This data has already allowed to draw up scheme of stadial disintegration of Holocene glaciation in the Tien-Shan mountains (see Fig. 2), which took place on decrementing basis [5].

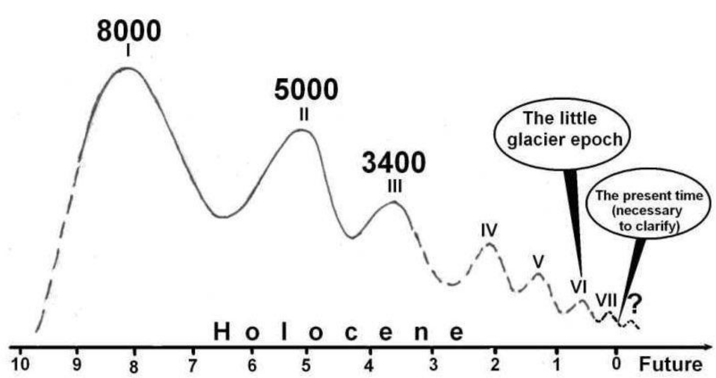


Fig. 2. Schematic model of long-term prognosis of natural glacial transformations: Horizontal axis – time scale (thousands years); I - VII – glaciation stages associated with morphologically articulated moraines of the Holocene glaciation; 8000, 5000, and 3400 – established radiocarbon ages of stadial moraines; ? – anticipated next stage of the Holocene glaciation.

According to this scheme, the last moraine line (situated outside the zero age mark) is a hypothetical one and is drawn extrapolatively, considering the morphologically pronounced regularity observed in reality. This line is a prognostic one and makes interest for long-term forecasting of glacial and climate changes, because the amplitude of this line (marking the next surge of modern glaciation) and the start time and duration of this surge will determine the climate and glaciation in the foreseeable future, not only in Tien-Shan, but in all of Central Asia.

This scheme can become the basis to be superimposed with anthropogenic factors of glacial and climate changes in Central Asia with the purpose to receive the reliable long-term forecast. Obviously, this scheme requires further elaboration aimed at establishing the ages of all other main (major), as well as secondary (minor) stadial moraines of the Holocene glaciation. Moreover, it is necessary to expand the geography of studies of the Holocene glaciation with the use of radiocarbon dating of dispersed moraine organics.

Literature

1. Shatravin V.I. *Fatsialno-litologicheskie osobennosti chetvertichnykh otlozheny vysokogornykh zon Severnogo Tyan-Shanya* (Facial-lithologic features of quaternary deposits of high mountainous areas of the Northern Tien-Shan). Summary of the thesis for the degree of candidate of geology and mineralogy. Institute of Geology of the Academy of Science of the Kyrgyz Republic. Bishkek, 1992. 21 pp.
2. Shatravin V. I. *Radiouglerodnoe datirovanie «nemyh» tolsch chetvertichnyh otlozhenii.* (Radiocarbon dating of "dumb" layers of the Quaternary sediments) // in: *Glavneishie itogi v izuchenii chetvertichnogo perioda i osnovnye napravleniya issledovanii v XXI veke* (The Main Results in the Studies of the Quaternary and the Main Directions of Studies in the 21st Century). (Abstract of presentation to the All-Union Consultations) VSEGEI. Saint Petersburg, 1998. – p. 55–56.
3. Shatravin V. I. *Radiouglerodnoe datirovanie moren po rasseyannoi organike*. (Radiocarbon dating of moraines on dispersed organics) // *Klimat, oledinenie, ozera Tyan-Shanya: puteshestvie v proshloe* (Climate, Glaciation, Lakes of Tien-Shan: Journey to the Past). Bishkek: "Ilim". 2007. pp. 74-92.
4. ISTC project #Kr-330.2. Final report. Bishkek, IWP&HP, Academy of Science of the Kyrgyz Republic. 2007.
5. Shatravin V. I. *Rekonstruktsiya pleistotsenovogo i golotsenovogo oledenenii Tyan'-Shanya s novyh ishodnyh pozitsii* (Reconstruction of Pleistocene and Holocene glaciation in Tien-Shan from new starting positions) // *Klimat, oledenenie, ozera Tyan-Shanya: puteshestvie v proshloe* (Climate, Glaciation, Lakes of Tien-Shan: Journey to the Past). Bishkek: "Ilim". 2007. pp. 26-46.

Long-term projections of glaciation and evaluation of glacial resources of Central Asia through isotope methods

Glaciers are the main source of renewable water and hydropower resources of the arid mountainous states of the Central Asia. The glacial runoff plays a significant part in the formation of the overall river runoff. In mountainous glacial system of Tian-Shyan, the glacier drain reaches for

64% of the whole flows of rivers [1]. The contribution of the glacial drain to the total inflow of the largest in the Kyrgyz Republic (KR) the Toktogul water basin reaches 29 %. [1]. Approximately 93 % of all electric power of Kyrgyz Republic is developed by hydroelectric power stations [2].

The decrease of a drain caused by climate change, already now causes interstate contradictions on a water question in the states of the Central Asia, in due course the opposition only will amplify. The glaciers of highlands will quickly degrade at global climate change. This will eventually result in reduction of the glacial runoff. In the nearest future, the Central Asian states will face a water, hydropower, and environmental catastrophe. In view of this, the ability to make reliable long-term climate and glaciation change forecasting is so important.

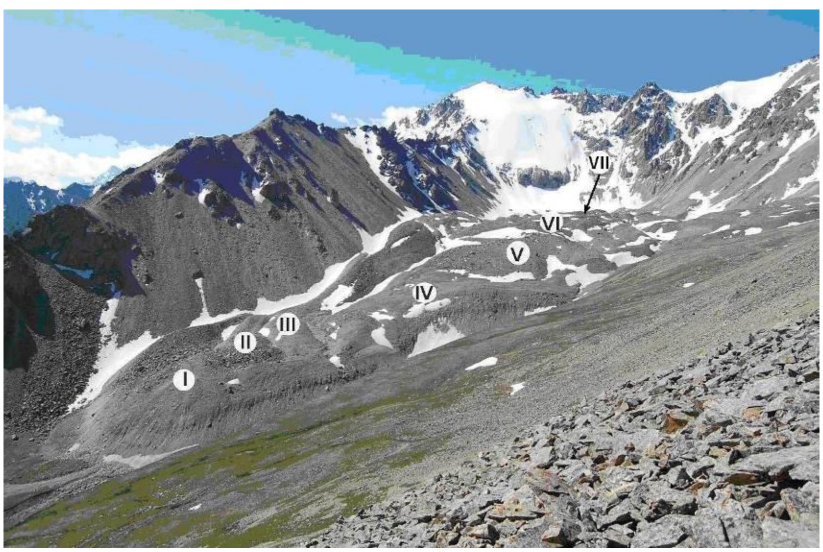
Errors in forecasting of dynamics of climate change are fraught with large economic accidents. Miscalculations of experts of 50-60th of last century, connected with falling of level of Caspian sea in 30 years have turned back of social and economic tragedy of the whole region. Reception of the reliable forecast will allow to take timely measures on adaptation in the conditions of a changing climate and to soften consequences of these changes.

The existing models of long-term glacial and climate change forecasting don't allow making reliable forecasts even for the next 100 years.

There are enough bases to guess that modern warming represents a part of a natural cycle of fluctuations of a climate. In this connection, a law of the natural climatic and glacial changes which were taking place throughout of the long period of time at least of Holocene (more than 10 thousand years) should be put in a basis of long-termed forecasting of a climate and a glaciation. By this time, such law isn't established because of imperfection of methods of dating of moraines. Moraines (glacial deposits) are reliable witnesses of last glaciation in this connection they are the major carriers paleoglaciological and paleoclimatic information. It is impossible to establish a law in disintegration time Holocene glaciation without absolute dates of moraines and to make reliable the forecast for the future too.

- Moraines are traditionally considered as chronologically "dumb" formations. All the present by this time absolute dates of moraines are unreliable for following reasons:
- They are either relative (in case of radio carbon method of dating of moraines with using of allochthonous organic substance) as it shows how much moraines are younger or ancient than this substance;
- Or they are received by physical methods of little use for dating of moraines.

Such dates are the cause of serious contradictions, which are taking place in paleoglaciological reconstruction. It will not be possible to construct the necessary long-term forecast on the basis of such dates. We have found a method of accurate evaluation of the age of moraines through radiocarbon dating of the autochthonous specific organic matter dispersed in moraines [3]. The method has been successfully applied in the ISTC project #Kr-330.2 in the Issyk-Kul basin [4]. Morphologically expressed law of disintegration of Holocene glaciation [5], in which it is allocated not less than seven basic stages (fig.1) has been established. It was demonstrated that the Holocene glaciation disintegrated in stages following fade-out scenario. For the first three (oldest) stadial moraines of this glaciation have been received radiocarbon dates. The schematic model of long-term forecasting of glacial changes (fig. 2) is constructed on the basis of received data [3].



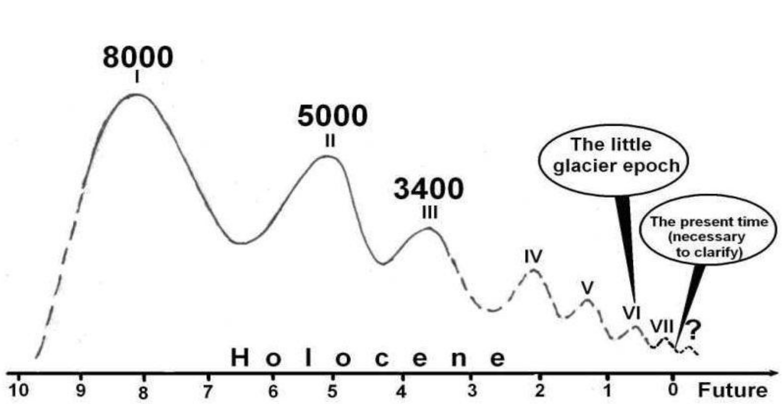


Figure 2. Schematic model of long-term prognosis of natural glacial transformations: Horizontal axis – time scale (thousands years); I - VII – glaciation stages associated with morphologically articulated moraines of the Holocene glaciation; 8000, 5000, and 3400 – established radiocarbon ages of stadial moraines; ? – anticipated next stage of the Holocene glaciation.

Dating of other stadial moraines is a way to long-term glacial and climate change forecasting. It is necessary to combine radiocarbon dates of the staged moraines with isotope-oxygen (on a parity of isotopes O16/O18) research of glaciers for more detailed paleoglaciological reconstruction of Holocene glaciation. It will allow defining temperatures of the climatic past.

Isotope-oxygen studying of glaciers became rather popular in glaciologists. On results of such researches do the big rate in business of paleoclimatic reconstruction and construction of the long-term forecast. With that end in view, in mountains of Eurasia a number of glaciers of Tien-Shan, Caucasus, Altai, Tibet, the Himalayas, Scandinavia, and Antarctica are drilled by this time. However, the weak place at isotope - oxygen studying of glaciers is a definition of absolute age of cores of ice. It becomes by means of models of a parity of age and depth of the glacial thicknesses constructed on the basis of characteristics of the ice flow. Thus, essential and theoretical assumptions are used. Therefore, establishing ages of cores are thus insufficiently authentic.

The way of radiocarbon dates of moraines offered by us will allow to date the isotope-oxygen curve (that is to adhere it to a reliable age scale) received at drilling of mountain glaciers. For this purpose, it is necessary to select series of samples on contacts of glacial ice and a superficial (ablative) moraine covering it (fig. 3). Samples of ice are for isotope-oxygen analyses and samples of autochthonic organic substance from moraines are for radiocarbon dates (fig. 4).

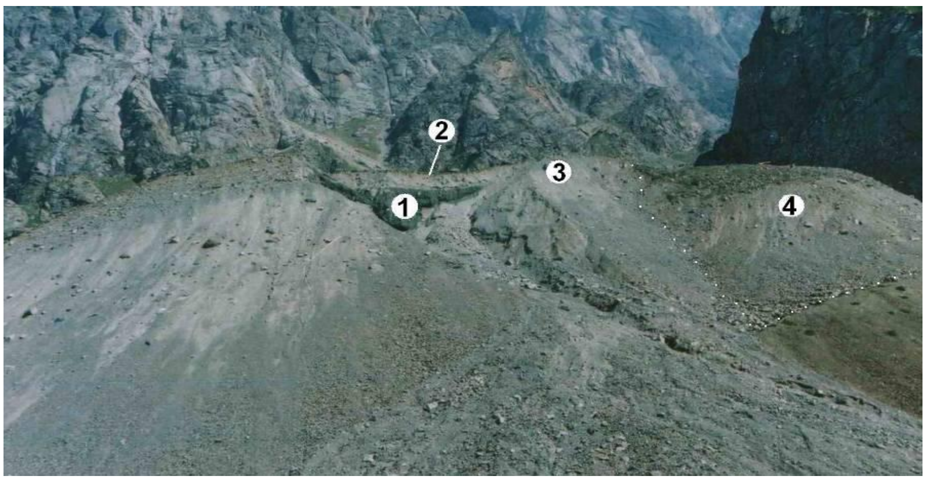


Figure 3. The frontal ledge of Holocene moraine-glacial complex in one of valleys of Northern Tien-Shan: 1 – exposure of glacial ice; 2 – ablative moraine; 3, 4 –stadial moraine-glacial generations.

The mountainous glaciers not only retreat, but also are being shielded with surface moraines. Both of them in the foreseeable future will lead to considerable reduction of a glacial drain. At first stages of reservation of glaciers (when the thickness of moraine cover is insignificant), their thawing is accelerated and the drain module is increased. Further, an increase of a thickness of moraine cover leads to delay of thawing of ice, up to its full termination. Glaciers thus appear as though preserved. It is important to make the long-term forecast not only the glaciation, but also booking of mountain glaciers and reduction in this connection glacial drain. How quickly will modern glaciers in the future "leave" under the moraine? What will affect more on a glacial drain – reduction of sizes of glaciers or their factor of reservation in the future? These questions demand the answer by studying of reserved glaciers, tendencies and speed of reservation in forecasting aspect.

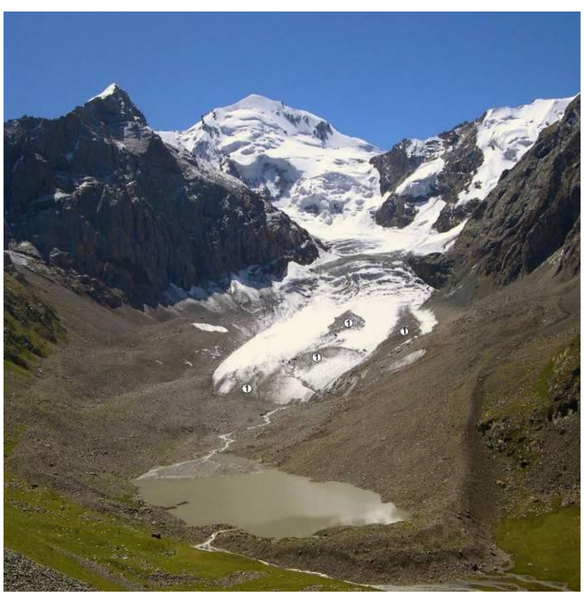


Figure 4.Moraine-glacial complex of Karabatkak, Basin Chon-Aksuu river, Teskey Ala-Too range.

The glacial drain from reserved parts of glaciers is in contact with moraines' adjournment and as it has been shown by us earlier [6, 7] leads to an increase of the isotope shift in uranium of glacial waters, i.e. to an increase not only of general maintenance of uranium in thawed snow, but also to a surplus increase of 234U in them. Statement of complex researches opened in various degree (on capacity of moraine cover) of reserved glaciers with use of isotope methods is necessary. It is necessary to study modern representative of moraine-glacial complexes as analogs of the future forecast objects. It needs to allocate morphologically well expressed uneven-aged (staged) and moraine-glacial generations in them and to define a share of actually glacial drain and a drain with reserved in various degree of moraine-glacial generations.

Even more often, there are messages on threateningly fast degradation of glaciers of Central Asia in some literature. So, in [8] it is possible to find the message that a thickness of Himalaya glaciers thaws with a speed of 10-15 m/year and 2/3 glaciers of China will disappear to 2060 and glaciers will thaw definitively to 2100. According to [9], the quantity of glaciers in Tien-Shan located in territory of Kyrgyz Republic can be reduced by 2100 by 10 times. Certainly, in these cases only open parts of glaciers meant therefore nobody was engaged in the reserved glaciers. In this connection, the forecast of glacial accident in above-stated sources is not far proved. For reception of an objective picture, it is necessary to be engaged in studying of reserved glaciers, including in historic-genetic aspect. It's required a revaluation of ice resources of the mountain areas resulted in the catalog of glaciers [9]. For this purpose, it is necessary to fulfill a technique of the account of volumes of the reserved glaciers. In the catalog of glaciers of Kyrgyz Tien-Shan [9] reserved glaciers haven't been considered. In this connection traditionally counted up ice resources are considerably underestimated and the component of a long-term frozen ground isn't considered . A key error [3, 5] is an acceptance of reserved Holocene glaciers for actually moraines that means the absence in them of buried ice, at the best is the presence of only ice fragments.

It was established by us that in mountains of Tien-Shan aren't separately taken Holocene glaciers and moraines and there are moraine-glacial complexes. On fig. 3 is shown a fresh uncovering of glacial ice in one of moraine-glacial complexes of Tien-Shan. Considerable stocks of ice are contained in these complexes in the form of reserved moraine covers of glacial bodies. Ice resources in moraine-glacial complexes are some kind of preserved stocks of ice, which give water by considerably smaller speed, rather than open glaciers. Their drain is rather uniform during all season of a year. On fig. 4 is the Holocene moraine-glacial complex of a glacier and Karabatkak lake, which are objects of studying and stationary supervision, fulfilled by the Laboratory of glaciology of TSHMSC at IWP&HP of NAN KR. On foreground (from different directions of lakes) is not moraines in habitual understanding, but they are the glacial bodies reserved by a moraine uneven-age of generation. They (and similar to them in other cases) haven't got to the catalog of glaciers of Tien-Shan. Only morained glacier sites named by authors [9] have entered into the catalog (on fig. 4 they are marked by figure 1 within a language part of a glacier).

For reception of long-term forecast of reservation of glaciers and reduction in this connection of the glacial drain, it is necessary to execute uranium-isotope researches on the moraine-glacial complexes in aggregate with morpholitological studying and radiocarbon date. Here, we start with the features established by us of glaciological litho genesis with formation of moraines of mountain glaciers at which the main role plays the organic material in a kind of glacio-chionophilous microorganisms living on glaciers. This organic material as well as any other organic substance sorbs uranium and its isotopes. Uranium-isotope researches will help to allocate uneven-age generation in Holocene moraine-glacial complexes and to establish a share of each component in general drain of the mountain rivers, including from the open and reserved parts of glaciers.

Conclusion

For the prompt decision of tasks, it is necessary to depart from traditional tendency to conduct infinite monitoring behind glaciers and a glacial drain. It could be go on for a long time without purpose achievement in the foreseeable future. By all instrumental researches over glaciers of Eurasia are engaged about 80 years since creation of glacial - hydrometeorological institutes on glaciers of Fedchenko (1933), Golubina (1937), Karabatkak (1947), Azau (1933), etc. During these monitoring was replaced some generations of researchers; however the long-term forecast of glacial and climatic changes necessary to mankind isn't received.

Now by the Kyrgyz and German efforts within of scientific programs CAIAG are created expensive automatic glaciometeorological observation stations on the Inylchek glacier. The situation of long-expensive building will also repeat in this case. It would be necessary to direct the enormous financial expenses not for on supervision, but on researches. The forecast is already necessary for people today and this problem becomes more and more sharp. It will be the resolute contribution to this business to pass from supervision to highly productive researches from the new positions developed by us, allowing to carry out correct paleoglaciological reconstruction and reliable date of Holocene and Pleistocene moraines. For this purpose, it is necessary to provide with due financing the above-stated researches, which materials can be found on a site www.glaciology.ru, www.scorcher.ru/glaciology/index.php) and to unite international efforts in this direction. And the result won't keep itself waiting.

Literature

1. Dikikh, A.N., Sokalskaya, A.M., Durgerov, M.B., and others (1995) Glacial runoff // Glaciation of the Tien-Shan. Moscow. – pp. 131-168.

2. http://www.regnum.ru/news/1236021.html

3. Shatravin, V. I. (2007) Radiocarbon dating of moraines with the use of dispersed organics // Climate, Glaciers, Lakes: Journey to the Past. Bishkek: "Ilim". pp. 74-92.

4. ISTC project#Kr-330.2 (2007) Final report. Bishkek, IWP&HP, Academy of Science of the Kyrgyz Republic.

5. Shatravin, V. I. (2007) Reconstruction of Pleistocene and Holocene glaciation in the Tien-Shan from new starting positions // Climate, Glaciers, Lakes of Tien-Shan: Journey to the Past. Bishkek: "Ilim". -pp. 26-46.

6. Tuzova, T.V, Shatravin, V.I. (1994) Specificities of formation of isotope composition of uranium in ices and waters of high-mountain cryolithogenesis // Izvestiya of Academy of Sciences of the Kyrgyz Republic, #3, -pp. 55-59.

7. Tuzova, T.V., Romanov, V.V, Vlasova, L.V. (1994) Uranium and tritium in glacial lakes of the Northern Tien Shan // Water resources, volume 21, #2, -pp. 236-239.

8. www.climatechange.ru/node/4; www.glaciology.ru; www.scorcher.ru/glaciology/index.php

9. Catalogue of the Tien Shan glaciers (1967) – Leningrad, volume 13, issue 2, part 1, 2.

Proposals to the Imja Lake Field Expedition (September 3-22, 2011)

It should be taken into account that alpine glacial lakes develop very dynamically and are outburst-prone. The life cycle of such lakes almost inevitably ends in an outburst. However, there are incidents of such lakes being restored and having repeated outbursts. One of them is the Merzbacher Lake (~300M m3) at the Inylchek glacier (Central Tien-Shan), which outbursts annually and then restores again. In view of this, there is a high probability that the Imja Lake will also outburst soon.

The character of glacial mud flows – water and stone (waterstone) flows (low-density, 1–1.15 t/m3) or mud and stone (mudrock) flows (high-density, up to 2–2.5 t/m3) – depends on presence of mud flow source or transformation points on their path. The main characteristics of mud flow-forming deposits are their granulometrical composition (most importantly, the presence of clay fractions). Mudrock flows are the most powerful and destructive. Water makes only 15–20% of the total mass of a mudrock flow. Mudrock flows are the most catastrophic, too.

In view of this, the following initial studies have to be carried out:

1. Survey the apron part of the Imja glacier to establish the degree of risk of the lake outburst:
    - Establish its thickness;
    - Establish presence and thickness of a moraine blanket;
    - Establish presence of funnel types of relief (thermokarst);
    - Establish the nature of lake water discharge (surface overflow, or inside-glacial discharge channels).

2. Conduct a preliminary geological-geomorhological survey of the water transit zone (in the event of potential lake outburst) and the areas that can be the source of mudrock flows. In doing so, the following should be established:

    - Presence in this zone of accumulative morpholithological formations made by loose clastic deposits in form of: glacial deposits (Holocene and Pleistocene moraines), gravitational deposits (landslides, landfalls, and polygenetic slope deposits), of proluvial deposits and other origin;
    - Presence of inflections of relief on substrates made of loose clastic sediments deposits, which can be a center of origin of mudrock flows.

Special attention should be given to presence of pseudo-moraines in the transit zone of the outburst water (pseudo-moraines are accumulative morpholithologic formations that only look like moraines, but are not of glacial origin). My studies demonstrate that their origin is mostly gravitational, in form of specific spatially developed landslides. Pseudo-moraines differ from real moraines by higher degree of clay content; therefore, they are an important source of mudrock slides. This is demonstrated by numerous (1921, 1956, 1973) catastrophic mudrock slides in the valley of the Malaya Alma-Atinka River (Zailiysky Alatay Ridge in the Northern Tien-Shan). For reliable distinction between moraines and pseudo-moraine, I have produced quantitative genetic indicators (geochemical and granulometric). With certain practice, the distinction can be done during the visual observations.

Remote Geohazards in Tajikistan: Assessment of the Hazards Connected to Lake Outburst Floods and Large Landslides in Selected Areas of the Pamir and Alai Mountains

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Remote geohazard events in the mountains of Tajikistan have repeatedly caused disasters during the past decades. The rock avalanche of Hoit (1949) with several hundred fatalities and the glacial lake outburst flood (GLOF) in Dasht in 2002, with dozens of fatalities, are only two examples. Though the possibility that such events may occur is known, the stakeholders and the people in the villages are hardly aware of specific remote geohazards. The present report highlights potential source areas and pathways of remote geohazard events in selected areas of Tajikistan, in order to allow for well-designed mitigation procedures.

A work flow for the assessment of mountain geohazards was developed (MoGAM – outlined in detail in a separate booklet) and applied. It includes a hazard assessment at the regional scale, a direct survey (from the helicopter and in the field), and a hazard assessment at the local scale. Particular methodical focuses are put on GIS and remote sensing techniques and on process modeling.

Particularly in the upper reaches of Rivakdara (Gunt Valley), a number of growing glacial lakes was identified. An outbreak of one of the glacial lakes could generate a flood wave weakening the composite dam of Rivakkul Lake, with catastrophic consequences for the population all the way downstream to the town of Khorog. Some more potentially hazardous glacial lakes drain directly and steeply into the villages of the Gunt Valley. Whilst most of these lakes are dammed by moraines – which may, however, contain some ice – some other lakes are dammed by glaciers or rock glaciers. The most significant example is located in Khavrazdara (Bartang Valley, Central Pamir), where the rock glacier dam appears stable at the moment, but further melting of the ice could lead to a sudden outbreak as soon as a certain threshold is reached.

In the highest portions of the Pamir, melting of the glaciers has not yet reached the stage as observed in the Southern Pamir. Glacial lakes just start to develop, but an accelerated evolution of glacial lakes in the area has to be expected in the future. In addition, surging glaciers in the area may lead to the quick development of new lakes. The Zarafshan and Turkestan Ranges in northwestern Tajikistan have experienced comparable processes some thousands of years ago, as indicated by geomorphologic records. However, damming of lakes by rainfall-triggered landslides has been reported repeatedly.

Two major tectonic faults run through the territory of Tajikistan, allowing earthquake magnitudes of up to 7.5 and more. Whilst the dams of some lakes may be weakened by earthquakes, or flood waves may be generated by rock falls into the lakes (this may be the case with the Seven Lakes in the Fan Mountains), several lakes dammed by earthquake-triggered landslides do exist (Seven Lakes) or have broken out

(Pasor-Ghudara Landslide). It is certain that new lakes will be dammed by earthquake-triggered landslides in the future, but the exact location of such events is hard to predict.

Modeling a Glacial Lake Outburst Flood (GLOF) from Palcacocha Lake, Peru

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Center for Research in Water Resources
The University of Texas at Austin

Introduction

Available data indicate that glaciers are undergoing a process of accelerated shrinking due to human intervention in the environment (IPCC, 2007). The biggest concentrations of ice sheets are located in Antarctica and Greenland. On the other hand, glaciers in South America represent just 3 cm of the sea level. Even though they make up a small proportion of global ice cover, they are critically important for human uses, including domestic, agricultural, and industrial uses, particularly in the equatorial tropical and subtropical latitudes (Casassa et al., 2007) since the glaciers in tropical latitudes have a buffer effect over the runoff.

Glaciers in the Andes of Peru provide fresh water for arid western Peru during the dry season when little or no rainfall occurs (Vuille et al., 2008). The west coast of Peru uses the water coming from the high mountains for agricultural, domestic, and industrial purposes. For example, in Peru the main source of electricity generation is hydropower, representing 80% of the electricity in the country (Vergara et al., 2009).

Georges (2004) cited by Vuille et al. (2008) estimated that the glacier-covered area in the Cordillera Blanca range of Peru had decreased from 800-850 km^2 in 1930 to 600 km^2 at the end to the 20th century. Racoviteanu *et al.* (2008) found 571 glaciers covering an area of 569 km^2 and experiencing a decrease in glacier area of 0.68% per year over the 33-year period 1970 – 2003, representing a 22.4% decrease in area over that period.

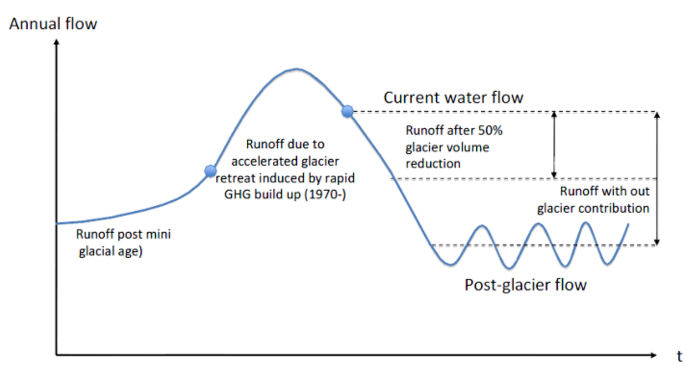

Figure 1: Impact of changes in glacier mass on runoffs (Source: Vergara, et al. 2009)

Figure 1 shows the general evolution of runoff due to glacier recession. Accordingly, an increase in runoff is expected during the first part of the retreat and an abrupt diminution of runoff in the latter part of the process. During the early stages, when runoff increases, there is a high risk of glacial lake outburst flooding of downstream zones adjacent to rivers. For example, Lake Palcacocha in Peru (Figure 2) was declared to be in an emergency state because its level is higher than the safe level (Diario La Republica, 2010). The risk now is that in the event of a landslide or ice avalanche into the lake, the moraine could fail, abruptly releasing a huge volume of water from the lake and creating a GLOF (Instituto Nacional de Defensa Civil, 2011).

In order to reproduce the behavior of an eventual GLOF at Lake Palcacocha, the aim of this study is to perform a 1D simulation of a GLOF using HEC-RAS for the hydraulic calculations and HEC GeoRAS for visualization. The study considers the GLOF to be composed of pure water, in this initial step, due to the difficulty of the problem analyzed and the complications of debris flow modeling.

Figure 2: Palcacocha Lake (photo by Colette Simonds).

Glacier Lake Outburst Flood

A Glacier Lake Outburst Flood is a sudden release of a huge amount of water, many orders of magnitude higher than the normal flow, from a lake formed at the snout of a glacier due to a breach of the moraine dam (Carrivick, 2006). According to Awal et al. (2010) it is common to find moraine-dammed lakes and GLOFs in different glacierized regions. In addition, Osti and Egashira (2009) point out that even though there is a great urgency to evaluate the impact of GLOFs and validate models that represent such events, it is difficult to obtain good approaches because of the lack of information. Attention has been primarily focused on past events, and satellite image information, but not on the hydrodynamic characteristics and continuum mechanics of the floods (Osti and Egashira, 2009). GLOFs can cause loss of life as well as losses in expensive infrastructure. According to Richardson and Reynolds (2000), cited in Bajracharya et al. (2007) and Osti and Egashira (2009), GLOFs represent one of the most significant glaciers hazards related to glacier recession and increases in temperatures due to climate change. GLOFs can affect fragile mountain ecosystems as well as economic activities due to the large magnitude of the flow (Bajracharya et al. 2007). For example, on December 12, 1941 a GLOF occurred from Lake Palcacocha in Peru (Figure 2) flooding the city of Huaraz and killing more than 5,000 people and destroying infrastructure and agricultural land all the way to the coast (Carey 2010). Many other regions with glaciated mountain ranges have experienced GLOF events, from Canada and Italy to Nepal and Peru (Bajracharya and Mool, 2009; Carey, 2005, 2010; Clague and Evans, 2000; Huggel et al. 2003; Kääb 2005; Richardson and Reynolds, 2000).

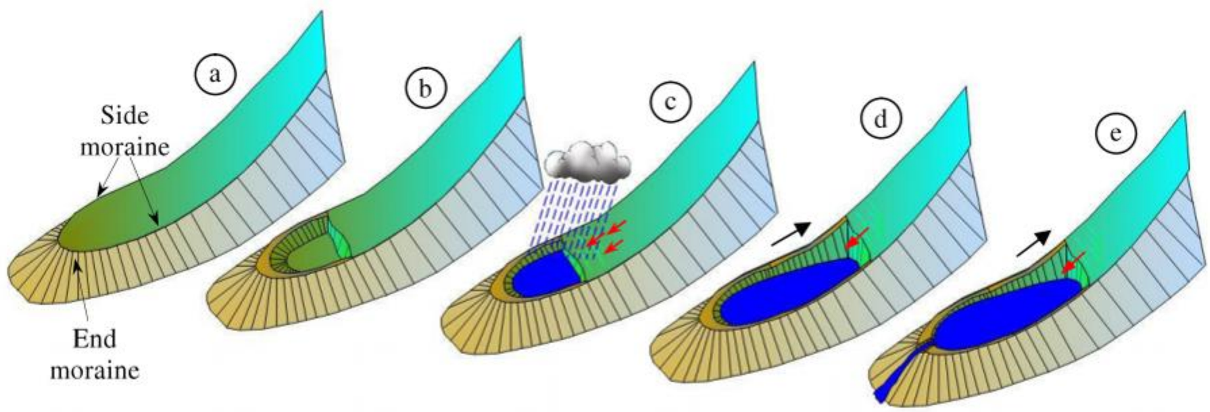

Figure 3: Formation of moraine-dammed lake (Awal et al. 2010)

Background

GLOF Trigger mechanisms

In order to breach a moraine, a trigger mechanism is needed. There are many different trigger mechanisms, including: waves generated by a snow or rock avalanche into a glacial lake, melting of the ice core of a moraine damming a lake, overtopping of a moraine due to intense rain or snow, earthquakes, etc. Even with the diversity of trigger mechanisms, waves produced by avalanches of ice and rocks are the main cause of breaches (Bajracharya et al. 2007). In a study of 20 GLOFs with identified trigger mechanisms, Bajracharya et al. (2007) concluded that 80% of the dam breaks where due to avalanches into the glacial lakes.

GLOF outflow hydrographs are functions of the trigger mechanism, overtopping due to wave generation from ice avalanches in most cases (75%). Additionally, the shape of the GLOF hydrograph is a function of the moraine breaching process, which is a function of the nature of the wave produced by an avalanche. Therefore, it is important to identify the characteristics, magnitude, and location of avalanches, in order to have a better understanding of GLOF characteristics (Bajracharya et al. 2007).

Dam Characteristics – In addition to trigger mechanisms, a GLOF hydrograph is highly dependent on the characteristics of the moraine dam. In this section, some of the results obtained by Awal et al. (2010) in an experimental study on glacial lake outburst floods due to waves overtopping and eroding moraine dams are discussed, and the effects of the shape of the moraine, the freeboard, and the slope of the upstream side of the dam are considered.

Moraine shape – Awal et al. (2010) compared triangular and trapezoidal dams and found that in both cases erosion of the dam started at the outer face of the dam. Triangular faces produce earlier and higher hydrograph peaks.

Freeboard – The magnitude of the waves generated by an avalanche falling into a lake depends on the size of the avalanche as well as the volume and depth of the water in the lake at the time of the avalanche. If the freeboard is small, it is more probable that the wave will overtop the moraine. Therefore, if the freeboard is small the dam is be more vulnerable to breaching.

Material of the moraine – According to Awal et al. (2010), the shear stress due to suction is an important factor of the velocity in a breaching dam. Also, the evolution of the breach is dependent on the particle size distribution, friction angle, cohesive strength, and non-homogeneity of the dam and its materials.

Slope of the inner face of the dam – The slope of the inner face of the dam is another factor that influences the failure mode of a moraine. The probability of dam failure increases with the slope. Smaller slopes result in later hydrograph peaks. Smaller volumes are drained from the lake when the slope is smaller because the depth of the breach will be smaller.

Study Area

Location

This study aims to estimate the impact of a potential GLOF from Lake Palcacocha located at an elevation of 4,567 m in the Quillcay catchment of the Cordillera Blanca in Peru. A GLOF from this lake may reach the city of Huaraz, as happened in 1941 with devastating consequences. The lake flows into the Quebrada Cojup, which drains to the Quillcay River. The Quillcay River passes through the City of Huaraz, giving its water to the Santa River, which is the main stream of the basin (Figure 4). Lake Palcacocha is of special interest since the city of Huaraz was devastated by a GLOF released from the lake on December 13, 1941, killing more than 5,000 people (Vilimek et al. 2005, Carey, 2010). In 1941, the lake had an estimated volume of 10 to 12 million m^3 of water (Report of Hazard 003-12/05/2011, National Institute of Civil Defense of Peru). In 1974, safety structures were built in the moraine dam of the lake in order to maintain a safe level of water in the lake (Figure 5). The safe level of the lake has been estimated to be around 0.5 million m^3; however, at the present time (2011) the volume is about 17 million m^3 (Table 1). Hegglin and Huggel (2008) concluded that at the time of their study Lake Palcacocha water had a high probability of reaching Huaraz since its volume was 3 million m^3. Therefore, with the current volume of 17 million m^3 there is no doubt that a GLOF would travel all the way down to Huaraz and cause significant damage and loss of life.

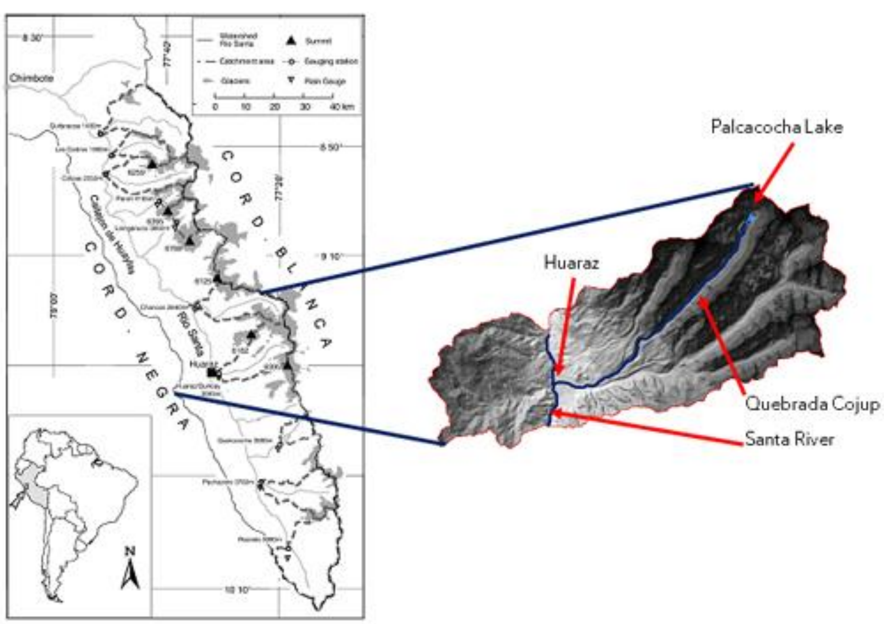

Figure 4: Map of the study area (Source: Georges, C. (2004). 20th-century glacier fluctuations in the tropical Cordillera Blanca, Peru. Arctic, Antarctic, and Alpine Research, 36(1):100–107)

a) b)

Figure 5: a) Hydraulic structures for draining water from Lake Palcacocha. b) Front view of the Lake in September 2004 showing the two artificial concrete dams (photo by Z. Patzelt 2004 cited in Vilimek et al. 2005).

Table 1: Volume of water at Lake Palcacocha (Source: National Institute of Civil Defense of Peru).

Year	Wide x Length m	Elevation masl	Area m^2	Volume m^3	Maximum Depth m
1972	390 x 220	4567	66,800	579,400	14
1974	420 x 250	4566	62,800	514,800	13
2003*	120 x 350	4566	342,332	3,959,776	15
2009	1600 x 437	4566	518,426	17,325,207	73

* There is some question about the accuracy of the 2003 values since they seem to have been taken after the 2003 GLOF event (personal communication, C. Portocarrero, Aug 3, 2011).

Climate

Andean Tropical Glaciers

Around 70% of all tropical glaciers are located in Peru. The most extensively glaciated mountain range is the Cordillera Blanca (Figure 4), which hosts nearly a quarter of all tropical glaciers. In comparison with alpine glaciers, which have a period of ice accumulation during the cold season and a short period of ablation in summer, the glaciers of the tropical Andes experience, in their lower part, an ablation regime throughout the year. In the higher part of the tropical glaciers of Bolivia and Peru the strongest ablation period coincides with the summer months of the southern hemisphere (October-April), and in Ecuador it coincides with the equinox months (April-May and September). In addition, the annual oscillation of temperature in those latitudes is insignificant compared with the diurnal oscillation (Coudrain et al. 2005).

Climate change and glacier retreat

It is widely known that glacier retreat in the warming tropical Andes has accelerated significantly in the past few decades, including the area surrounding Lake Palcacocha (Figure 6).

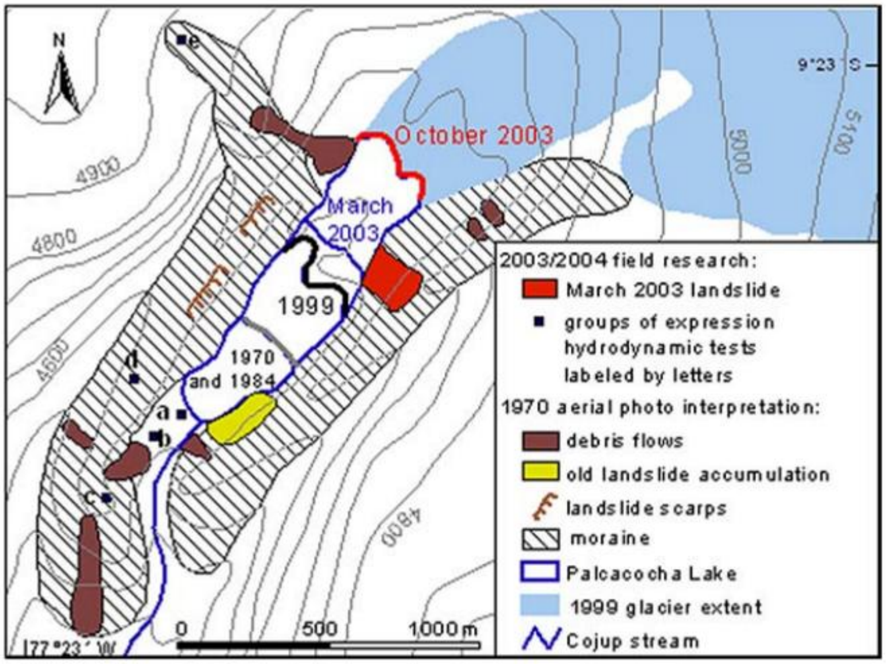

Figure 6: Glacial retreat history between 1970 and 2003 for Lake Palcacocha vicinity (Vilimek et al. 2005).

It is more difficult to relate the fluctuations of mass balance for tropical glaciers to climatic changes than for mid-and high latitude glaciers because they do not depend primarily on the fluctuations in local temperature; on the contrary, the most important factors may be those that drive albedo. Vuille et al. (2008) pointed out that the temperature in the tropical latitudes will increase around 4-5°C by the end of this century, but the consequences of this temperature increase on tropical glaciers are not easily predictable since temperature and sensible heat transfer do not play such a dominant role as they do for mid-latitude glaciers. Also, the processes are more complex in the tropics because the increase in melting indicates a complex combination of factors related to the energy balance, such as temperature, duration of dry events, precipitation, and humidity which control albedo, and melting/sublimation (Coudrain et al. 2005). Moreover radiative fluxes and turbulent latent heat flux appear to dominate the glacier surface energy balance (Vuille et al. 2008).

Relationship with regional-scale climate

Even though temperature is not the most important variable of tropical glacier energy balance, it plays an important role in the mass balance, because temperature is strongly related to other parameters that have a more direct relationship with mass balance, such as humidity (Figure 7). When the air is cold, it is wet and when the air is warm it is dry (Vuille et al. 2008). Even though temperature is not the driver in the glacier recession process, it may be used as an indicator of humidity. According to Vuille et al. (2008) "This behavior makes the attribution of mass balance variations to individual climate parameters more difficult, because years with increased accumulation are also commonly characterized by reduced melt, while ablation is usually enhanced in years when snowfall is already low."

Even though there is this correlation between temperature and humidity, precipitation is a better indicator of tropical glacier dynamics than temperature. There is a positive correlation between precipitation and glacier mass balance. In addition, there is a negative correlation between vapor pressure at the surface and glacier mass balance. If the vapor pressure is high the gradient of latent heat flux will be smaller, and as a result, sublimation will be limited and the available radiative energy will be consumed by melting, which is about 8.5 times more energy efficient than sublimation, causing higher overall mass loss (Kaser et al., 1996b, 2005; Wagnon et al., 2001; Sicart et al., 2005; Vuille et al., 2008).

El Niño Southern Oscillation (ENSO) effects

Andean glacier retreat has not been uniform throughout the 20th century. The glacier mass balance appears to be controlled by decadal climate oscillations driven by the El Niño Southern Oscillation mechanism. During El Niño events, the temperature increases and the precipitation decreases in the tropical areas; as a result, the glacier mass balance becomes negative. On the other hand, during La Niña events, temperatures decrease and precipitation increases; as a result, the glacier mass balance becomes positive. According to Coudrain et al. (2005), intertropical glaciers may lose from 600 to 1,200 mm of water equivalent during El Niño periods.

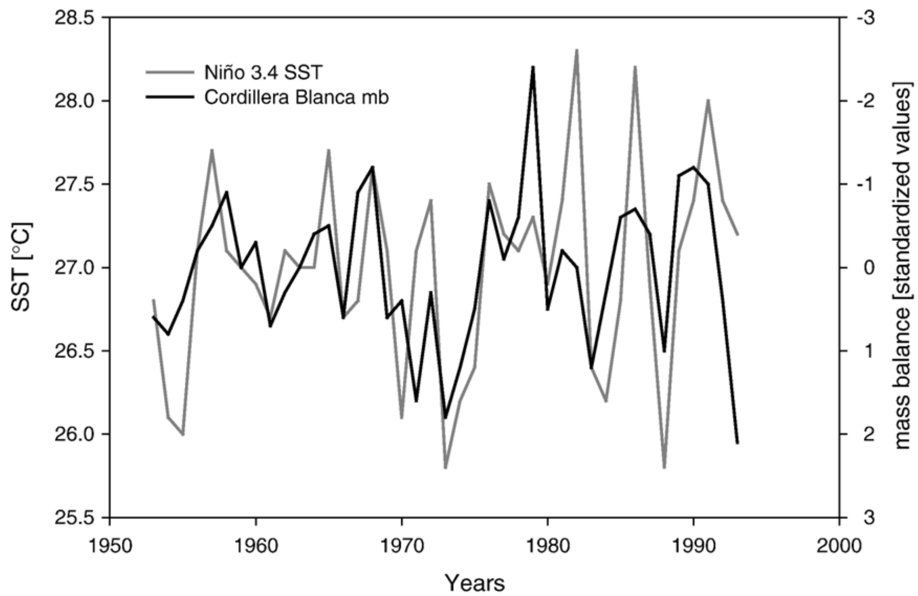

Figure 7: Correlation between annual (Oct.–Sept.) Cordillera Blanca mass balance time series in black (standardized values) and ONDJFMA Niño-3.4 index in gray (in °C). Years refer to OND part of the year; hence 1960 refers to 1960/61. Please note that scale for mass balance is reversed (Vuille et al. 2008).

Another indicator of glacier retreat acceleration in the tropical areas is that warm ENSO events have occurred with higher frequency during the last 20 years. Specifically, the temperature has been abnormally warm for more than 15 years, while cold conditions were more frequent during the 1956 to 1976 period (Figure 8).

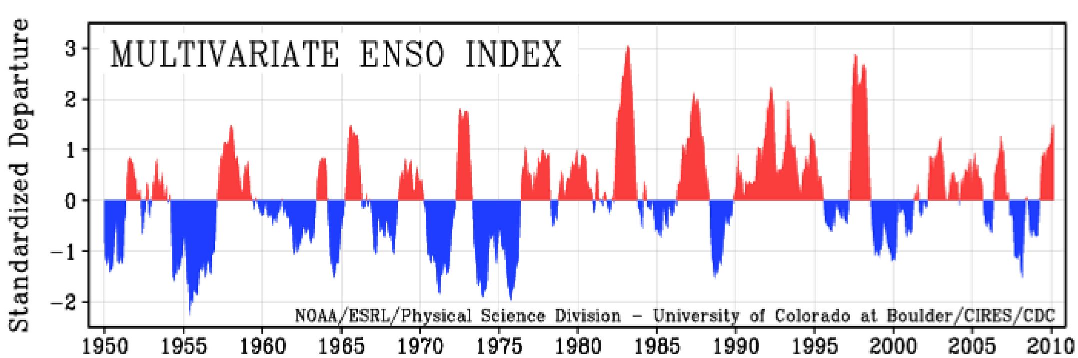

Figure 8: Multivariate Enso Index. (http://www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/)

Projected Temperature Changes

According to Bradley et al. (2004) who analyzed mean monthly temperature from seven coupled atmosphere-ocean general circulation models, the temperature in the next eight decades will increase. Also, larger increases in temperature are expected at higher altitudes. Coincidentally, glaciers in the subtropical areas are located in higher elevations; therefore, these glaciers will experience higher increments of temperature.

GLOF modeling

Physical Information

For this study, a 30m x 30m resolution digital elevation model (DEM) was used (ERSDAC, 2010) (Figure 9). HEC-GeoHMS (USACE 2010b) was used in ArcGIS to delineate the river basin. Also, a drainage line dataset created by the Geographic-Military Institute of Peru was used to correct and verify the DEM information. That dataset provides, among other things, the streamline of the Cojup Creek and the Quillcay River considered in this study as well as the streamline of the Rio Santa.

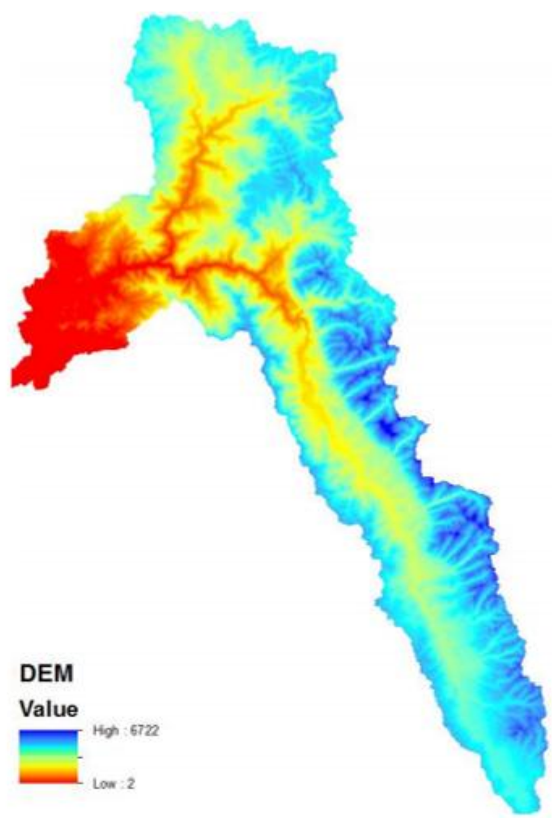

Figure 9: Digital elevation map of the Santa River basin at 30-m resolution

The delineated reach has a length of 22 km from the Lake Palcacocha moraine to the Santa River at Huaraz. Due to the coarse resolution of the DEM the information obtained for the Quillcay River at Huaraz and the associated floodplain was not included since it was clearly inaccurate (Figure 10). The flow paths, banks, and Lake Palcacocha moraine (dam) were digitized using Google Earth. Then HEC Geo-RAS (USACE 2009) was used to extract 178 cross sections from the DEM.

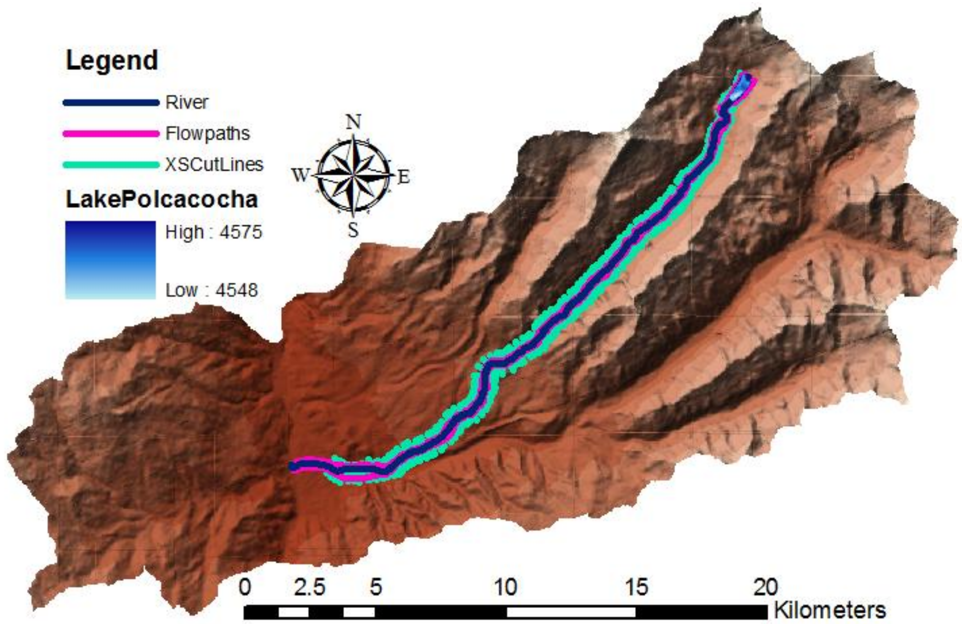

Figure 10: Output from HEC Geo-RAS.

Hydraulic calculation

HEC-RAS model has been used to perform the hydraulic calculations of the potential Lake Palcacocha GLOF. Due to the unstable nature of the dam breach process the model parameters were calibrated to achieve greater stability rather than accuracy in the solution, since the terrain data is of coarse resolution (30m). HEC-RAS reference manual recommends DEM resolution of no more than 10m. The stability of the model is a function of the distance between the cross-sections and the time step used in the simulation. The minimum time step allowed in HEC-RAS is one second, which was used here. In addition, cross-section interpolations were performed in the locations where the solution becomes unstable.

As mentioned above, the current (2011) volume of water in Lake Palcacocha is about 17 million m^3. In order to calibrate the outflow hydrograph from the dam breach an empirical equation is used. For simplicity, Popov's relationship $Q_{max} = 0.0048V^{0.896}$ where Q_{max} (m^3/sec) is the peak discharge from the breach and V (m^3) is the volume of the lake (Popov, 1991 as cited in Huggel et al., 2002). The resulting peak discharge is 14,445 m^3/sec from the moraine breach. In order to obtain a similar value as a peak outflow in HEC-RAS, the dam breach was set as shown in Figure **Error! Reference source not found.**11. The full formation of the breach takes 30 minutes. The breach is produced by overtopping since this is the most probable case. The depth of the breach is 35 m high, with a bottom width of 50 m. The river was considered wet at the beginning of the simulation with an initial flow in the river of 200 m^3/sec. Another important parameter is the Manning roughness coefficient (*n*). Manning's *n* was considered homogeneous for the entire river with a value of 0.05. This value is recommended for mountain streams (Chow 1959).

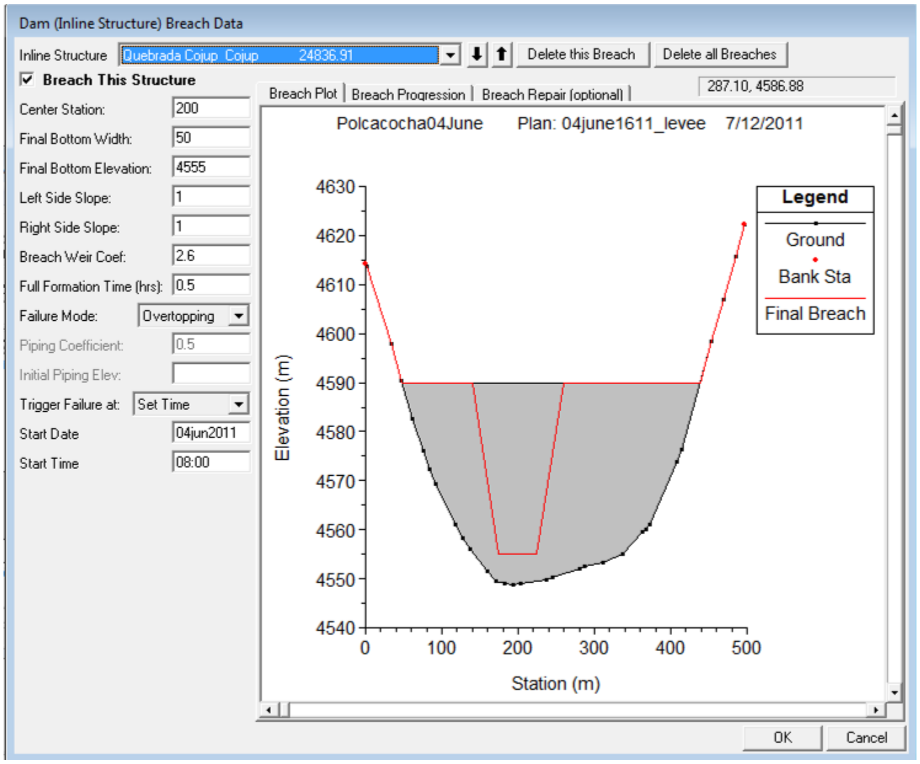

Figure 11: Dam breach input data

Results

As mentioned above, the time for the moraine to breach is 30 minutes. The outflow peak occurs 22 minutes after the start of breaching. The peak flow rate is 14,476 m^3/sec, which is very close to the peak calculated with Popov's equation. Figures 12 and 13 show the water elevation and flow rate at the dam cross section and the last cross-section in the Quillcay River downstream. The lag time between the peak flow at the dam and the peak flow at the downstream cross section is 20 minutes. Hence, the dam breach wave traveled 22 km in 20 minutes (66 km/hr). The volume of water released from the dam is about 15.5 million m^3. Almost all of that water passed through the downstream cross section; therefore, there were not significant losses due to accumulation along the river. Due to the steeply sloped terrain, the flow is supercritical most of the time. Figures 14 and 15 show that the HEC-RAS calculations are consistent since the maximum water velocities agree with the higher slopes.

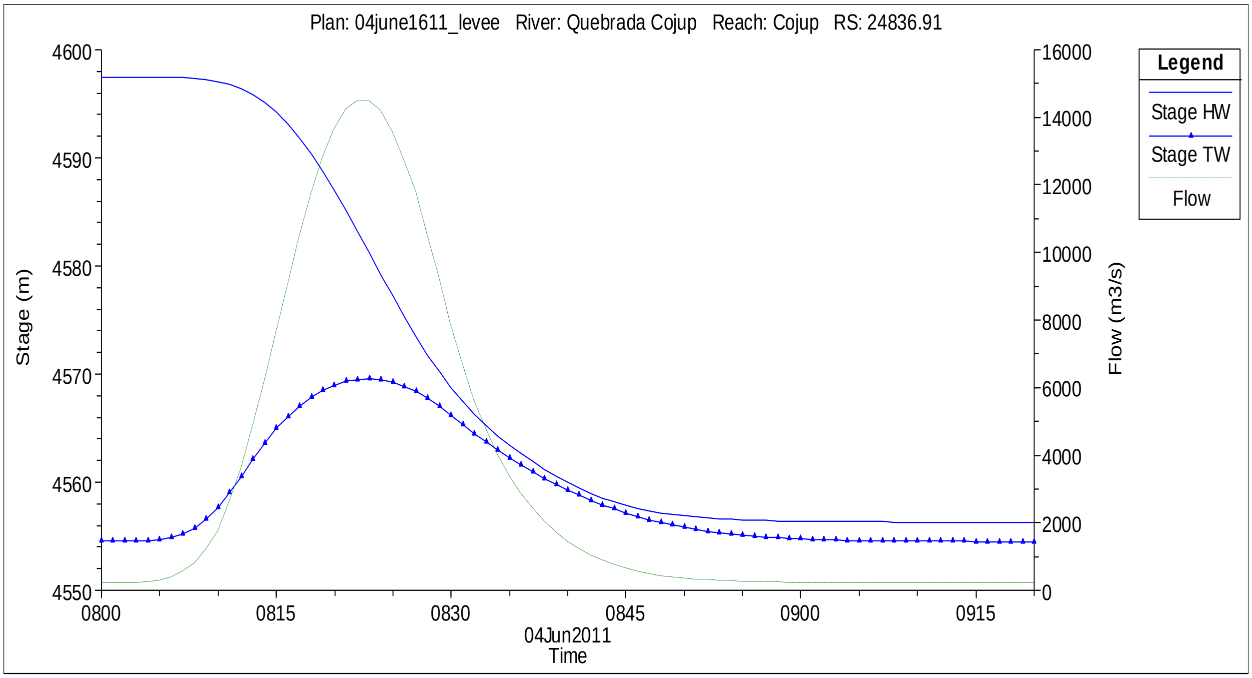

Figure 12: Dam breach hydrograph. HW: headwater, TW: tailwater

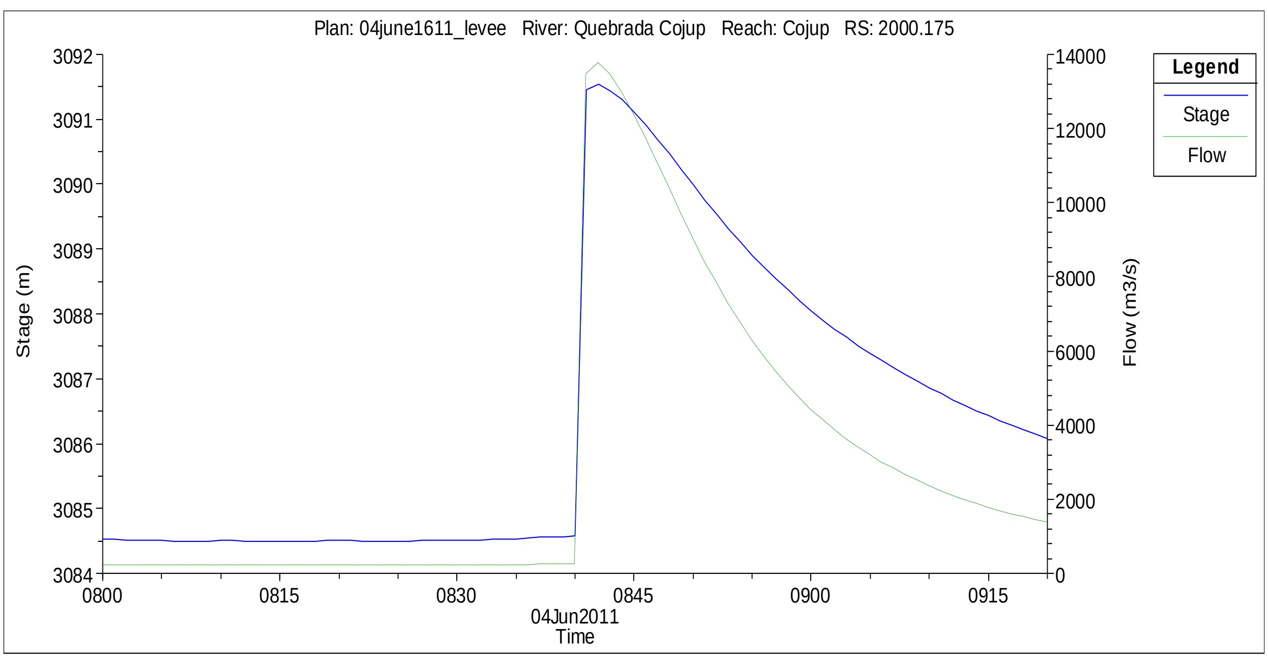

Figure 13: Downstream cross section hydrograph

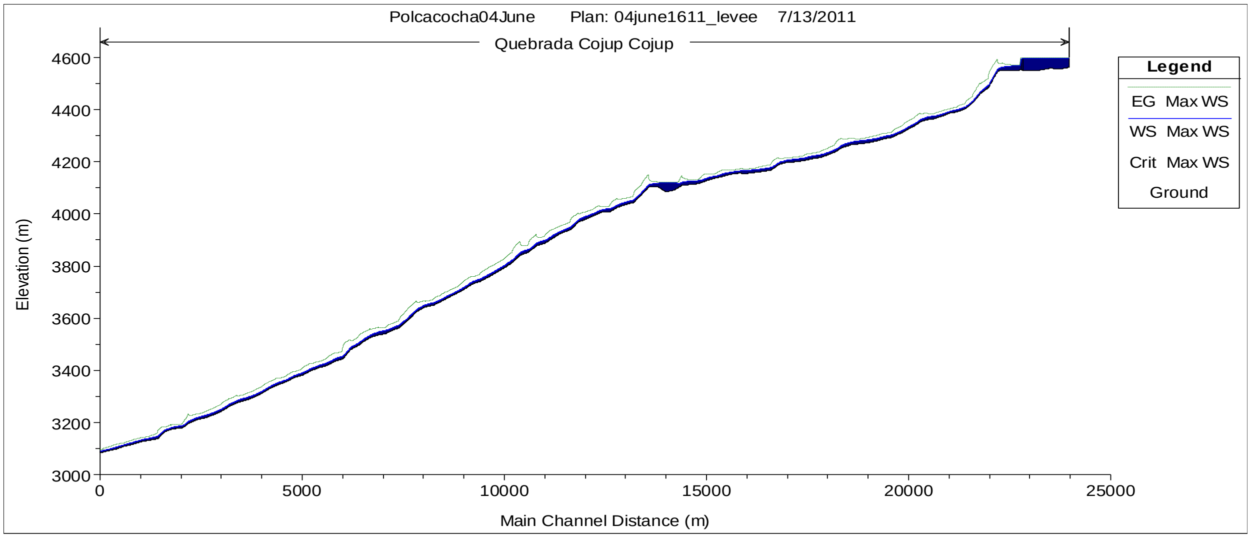

Figure 14: Longitudinal profile of the maximum flow.

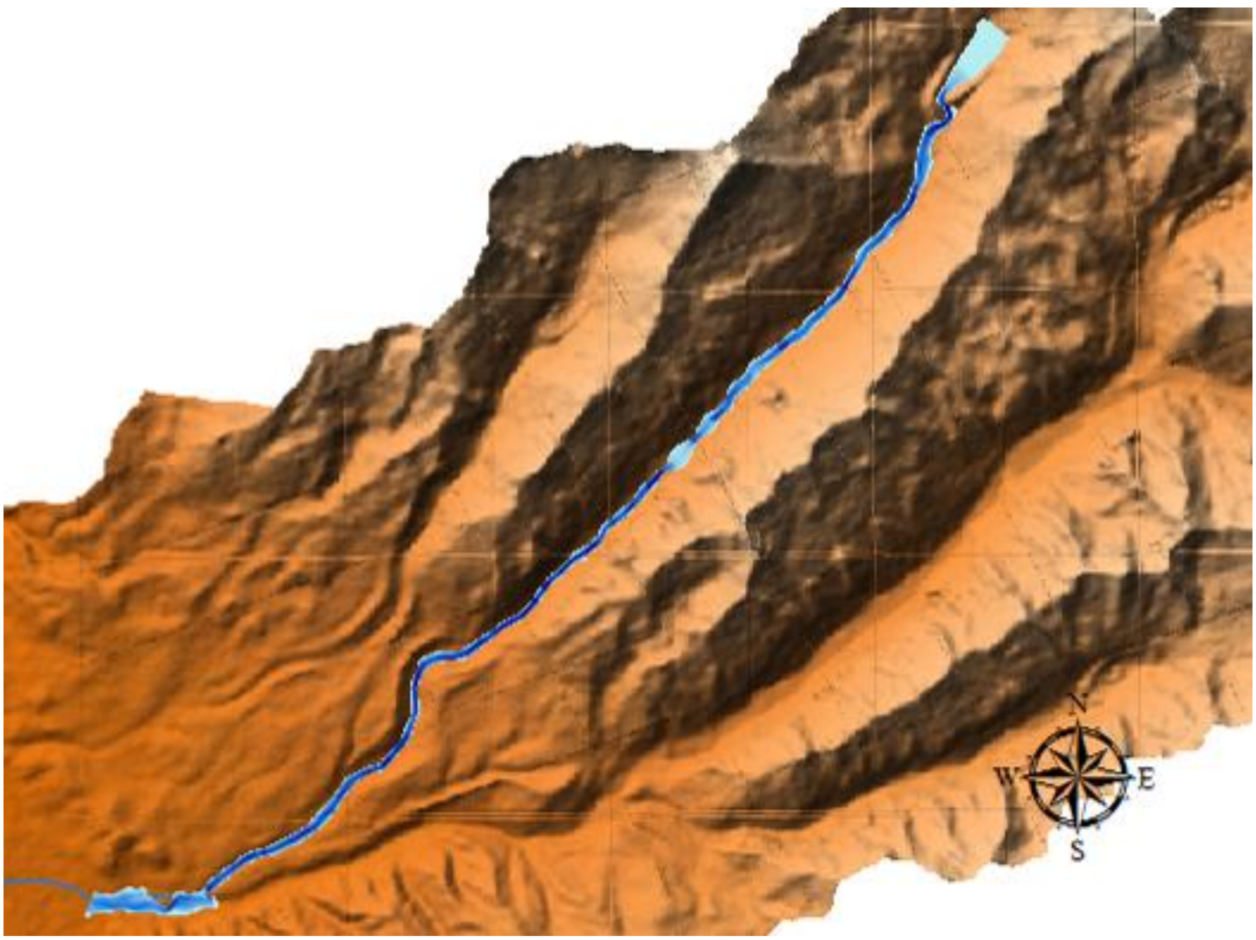

Figure 15: Aerial view of the maximum inundation.

Conclusions and Future Work

This work was performed with little information. The results obtained are preliminary, without much calibration due to the lack of detailed terrain data. It is important, in order to increase the accuracy of the result, to obtain more detailed terrain data from surveys or Lidar. Paleoflood information would also be useful for calibration as well as terrain marks from the GLOF that occurred in 1941. Knowing the characteristics of the dam is important: materials, dimensions, slope of the wall, etc. The characteristics of the Quebrada Cojup are important, an adequate Manning coefficient needs to be estimated. In addition, it is important to have terrain data for the city of Huaraz and the confluences of the Quillcay River and the Quebrada Cojup as well as the Quillcay River and Santa River. All of that information is the basis for improving what has already been done. The next step for this work is to perform a simulation that includes the debris flow in order to obtain a more realistic solution for the GLOF problem. In addition, it is important to perform two-dimensional simulations and, less probable, three-dimensional simulations in order to have a more detailed representation of the problem. It is important also to investigate and perform simulations with different roughness models that may be applicable to GLOFs in regions with steep slopes. This is more complex numerically and will demand better information; therefore, it will be integrated into this study when the one-dimensional solution includes adequate input information. Finally, a vulnerability assessment should be carried out at the end of this work. In this study it was possible to determine that the flood wave takes 20 minutes to reach the city of Huaraz, which gives a time period for planning an evacuation. This would allow developing a zoning map of the city to be elaborated, or an alarm system in case an avalanche is detected and so on. At this point, there remain many questions about this work; this is just the first step.

Bibliography

Awal, R., Nakagawa, H., Fujita, M. K., Baba, Y., & Zhang, H. (2010). Experimental study on Glacial Lake Outburst Floods due to waves overtopping and erosion of moraine dam. *Annuals of Disas. Prev. Res Inst. Kyoto University* , 583-594.

Bajracharya, B., Shrestha, A. B., & Rajbhandari, L. (2007). Glacial Lake Outburst Floods in the Sagarmatha Hazard assessment using GIS and Hydrodynamic Modeling. *Mountain Research and Development , 27*, 336–344.

Bradley, R., Keimig, F., & Diaz, H. (2004). Projected temperature changes along the American cordillera and the planned GCOS network. *Geophysical Research Letters , 31*, 1-4.

Carrivick, J. L. (2006). Application of 2D Hydrodynamic modeling to high magnitude outburst floods. An example from Kverkfjoll, Iceland. *Journal of Hydrology , 321*, 187-199.

Chow, V. T. (1959). *Open Channel Hydraulics.* Caldwell, New Jersey, USA: The Blackburn Press.

Coudran, A., Francou, B., & Kundzewicz, Z. (2005). Glacier Shrinkage in the Andes and consequences for water resources. *Hydrological Sciences Journal , 56* (6), 925-932.

Diario La Republica . (2010-20-04). *La Republica.* Retrieved 2010-24-04 from www.larepublica.pe: http://www.larepublica.pe/regionales/20/04/2010/declaran-en-emergencia-la-laguna-palcacocha-en-huaraz.

Editorial. (2007). Current status of Andean glaciers. *Global and Planetary Change , 59*, 1-9.

Hegglin, E., & Huggel, C. (2008). An integrated assessment of vulnerability to glacial hazards. *Mountain Research and Development , 28*, 299-309.

Huggel, C., Kääb, A., Haeberli, W., Teysseire, P., & Paul, F. (2002). Remote sensing based assessment of hazards from glacier lake outbursts: a case study in the Swiss Alps. *Canadian Geotechnical Journal , 39*, 316-330.

Instituto Nacional de Defensa Civil. (2011). *Informe de peligro N° 003-12/05/2011/COEN-SINADECI/ 15:00 horas (Informe N° 01): Peligro por aluvión en el departamento de Ancash*. Huaraz-Peru: COEN-SINADECI.

Intergovernmental Panel on Climate Change . (2007). *Climate Change 2007: Syntesis Report.*

Osti, R., & Egashira, S. (2009). Hydrodynamic characteristics of the Tam Pokhari Glacial Lake Outburst Flood in the Mt. Everest region, Nepal. *Hydrological Process , 23*, 2943-2955.

US Army Corps of Engineers Hydrological Engineering Center. (2009). *HEC-GeoRAS (version 4.2) GIS tools for Support of HEC-RAS using ArcGIS® User's Manual* . Davis, Ca, United States.

US Army Corps of Engineers Hydrological Engineering Center. (2010). *HEC-RAS River Analysis System Hydraulic Reference Manual (Version 4.1)*. Davis, CA, United States.

US Army Corps of Engineers Hydrological Engineering Center. (2010). *HEC-RAS River Analysis System User's Manual (Version 4.1).* Davis, CA, United States.

Vergara, W., Deeb, A., Valencia, A., Haeussling, S., Zarzar, A., Bradley, R., et al. (2009). *Assessing the Potential Consequences of Climate Destabilization in Latin America. The World Bank Latin America and the Caribbean Region. Sustainable Development working paper*. The World Bank Latin America and the Caribbean Region.

Vilımek, V., Zapata, M. L., Klimes, J., Patzelt, Z., & Santillan, N. (2005). Influence of glacial retreat on natural hazards of the Palcacocha Lake area, Peru. *Landslides , 2*, 107–115.

Vuille, M., Kaser, G., & Juen, I. (2008). Glacier mass balance variability in the Cordillera Blanca, Peru and its relationship with climate and the large-scale circulation. *Global and Planetary Change, 62*, 14-28.

Zhou, R. D., Judge, D. G., & Donnelly, C. R. (2005). Comparison of HEC-RAS with FLDWAV and DAMBRK models for dam break analysis. *CDA2005 Annual Conference.*

The Sounds of a Glacier: Applied Acoustemology on the Imja Lake Expedition

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I accompanied The Mountain Institute-led expedition to Imja Lake and the greater Khumbu this September to make location recordings for an experimental phonography project, which will culminate in a series of sound works and events over the course of the coming year. I have done most of my sound work to-date in the mountainous regions of Nepal and I compose these works using a variety of guiding logics, some of which prioritize sound qua sound, but very often I take into account how local associations with the aural environment contribute to create culturally meaningful experiences of place. I took keen interest in going with this international expedition of engineers, geographers, and scientists because I believed that by acoustically conveying their perceptions of the Khumbu, and the challenges presented by its melting glaciers, I could conceptually bridge local and global perceptions of the rapidly changing Himalayan environment with universal concerns about our world at large. Thanks to Dr. Alton Byers of The Mountain Institute, who encouraged my participation, to partial funding from the Anthropology Department at Harvard University, and to access to professional sound recording equipment from The Film Study Center, I now have many hours of new high-quality sound recordings, which I will use to construct hybrid sound works. These recordings include hours of interviews with expedition participants, stereo sound recordings made while on the trail, in the towns along the route, of windy alpine landscapes, and rock fall on glaciers, as well as recordings I made with hydrophones in a number of water bodies in the Khumbu.

I intend for my work from this expedition to take shape in a variety of pieces and contexts: there will be an interactive media work published on sensatejournal.com that will combine still images, video, and layered sound works, which I will compose from the recordings I made during the trip; an album with original soundscapes; a sound installation, which I would like to make in Boston, perhaps in conjunction with other work at Studio Soto; and, if the US State Department remains interested, I would like to collaborate with Dr. Alton Byers to create a soundscape that will animate pairs of images, archival photographs from the 1950s, and Byers' repeat digital images of these dramatic Himalayan panoramas.

Aside from these tangible products, the expedition was productive for me both intellectually and artistically. I am more certain that following the completion of my doctoral degree, I will increasingly shift the focus of my work toward an anthropology of science, and knowledge production more generally, and that my art work will increasingly reflect these inquiries in both content and form. In my sound work, I will continue to listen and craft pieces from mountain environments and will concentrate more intently on the ways we humans seek to understand our rapidly changing world through cultural practices and scientific methods. I look forward to future collaborations with the individuals and communities this expedition brought together.

Glacial Lake Inventory of the Hindu Kush-Himalayas

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International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal

Introduction

After the severe impact of the 1985 Dig Cho glacial lake outburst flood (GLOF) (Ives, 1986; WECS, 1987; Yamada, 1998), a joint expedition was organized by China and Nepal to study glacier and glacial lakes in Pumqu (Arun) and Poiqu (Sun Koshi) river basins in China in 1987 (Liu and Sharma, 1988). The first glacial lake inventory has was done based on topographic maps of the 1980s and, aerial photographs from 1974. After that, a series of glacier and glacial lake inventories were carried out by ICIMOD and its regional member countries (RMC) in Bhutan, China, India, Nepal, and Pakistan. The inventory for Nepal and Bhutan was started in 1999 based on topographic maps from between 1950 and the 1970s in cooperation with the United Nations Environment Programme/Regional Resources Centre for Asia and the Pacific (UNEP/RRC-AP), and published in 2001 (Mool et al., 2001; Mool et al., 2001). Inventories for selected basins in China, India, and Pakistan were started in 2002 based on satellite images taken between 2001 and 2003, with the support of Asia-Pacific Network for Global Change Research (APN), the global change SysTem for Analysis, Research, and Training (START), and UNEP/RRC-AP (Bhagat et al., 2004; Mool and Bajracharya, 2003; Roohi et al., 2005; Sah et al., 2005; Wu et al., 2003).

Although regional glacial lake inventories have been carried out in most areas of the Hindu Kush-Himalayas (HKH) region, still it remains urgent to obtain integrated glacial lake inventory data for the whole HKH region. The existed existing data and satellite-based method provides a quick way method for glacial lake mapping on a large scale in the HKH region.

The study area

The Hindu Kush-Himalaya (HKH) is a mountain system extending from the south to central Asia, and includes the Hindu Kush Mountains, the Karakoram Mountains, and the Himalayan Mountains. The extensive HKH, also known as the Greater Himalayas, also contain include Pamir and Tibet au and it is the target area of ICIMOD (ICIMOD, 2010). It is the source of ten 10 large Asian river systems and provides water, ecosystem services, and the basis for livelihoods to a population of around 210.53 million people in the region. The Hindu Kush-Himalayan HKH holds one of the most widely distributed areas of glacial lakes in the world, in addition to besides the Andes, central Asia, and North America (Clague and Evans, 2000). In this project, focuses on only a narrow strip of the HKH region is focused on. The study area is located between 62.8°N - 99°N in longitude and 25.5°E -38.8°E in latitude with an area of 91192km^2. Figure 1 shows the study area and related basins of this project. This study area extends from east to west about 2,800 km and covers the area of seven countries- –Afghanistan, Pakistan, India, China, Nepal, Bhutan, and Myanmar.

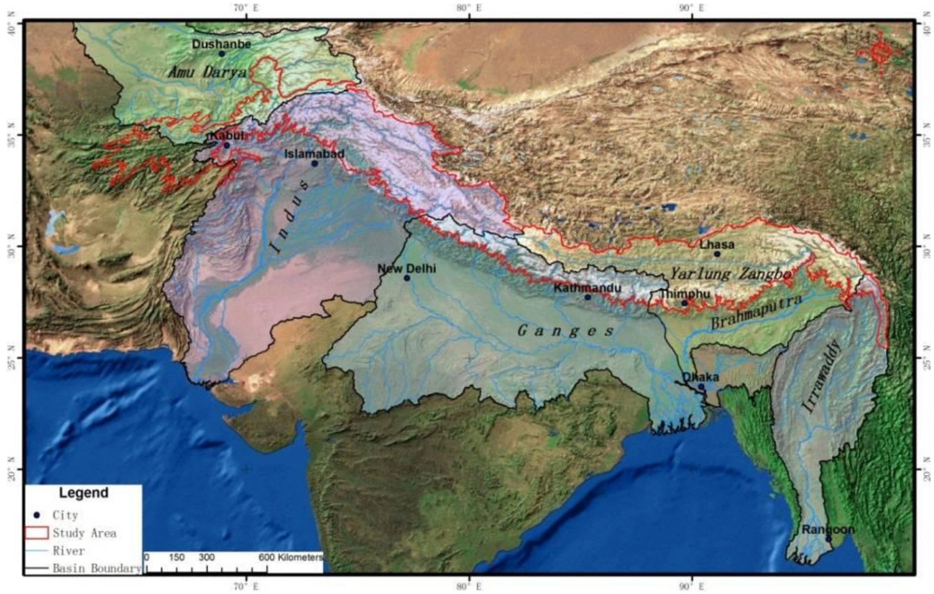

Figure 1 The Study Area

Method and Datasource

The object of a glacial lake inventory

In limnology, the a glacial lake is defined as a water body in the landform formed by glaciation. In the northern hemisphere, many large lakes are formed by paleoglaciation. For GLOF, moraine -dammed lakes and ice- dammed lakes are the biggest threats to people and property in mountain regions. However, debris flows triggered by floods have repeatedly caused disasters in high-mountain regions. The HKH is the broadly distributed region of periglaciated area outside high-latitude area. Rock debris are is produced, deposited, and deformed over time scales of centuries to millennia in the periglacial alpine environment (Frauenfelder et al., 2008). The water body formed on periglacial landform is also a kind of trigger or catalyst for debris flows. BesidesIn addition, lakes in the downstream of a dangerous lake can also be destroyed by the flood waves and give rise to more damage on to human lives and infrastructure. Therefore, the object of a glacial lake inventory includes all the water bodies in a glaciated area. In the HKH region, as the lowest snowline can reach 3000m a.s.l (above sea level), it's it is better to register all lakes above 2,500 m.

Method and Data source

Many satellite-based methods have been developed for detecting glacial hazards detecting have been developed(Huggel et al., 2002; Huggel et al., 2006; Kääb, 2000). The "'Normalized Difference Water Index"' (NDWI) method provides a automatically way to detect a glacial lake on the basin of Landsat Thematic Mapper (TM) or Enhanced Thematic Mapper Plus (ETM+) images (Huggel, 1998). However, since the low resolution of Landsat images can result in more error if the glacial lake is smaller than 0.1km^2 and will impact the result while comparing when compared with historic glacial lake inventory data (Paul et al., 2002). So, it's better to use high satellite image such as QuickBird and SPOT image.

Due to the limited budget and the large size study area, the Landsat TM/ETM+ that can could be downloaded freely from NASA or United States Geological Survey (USGS) are the only data sources for glacial lake mapping in HKH region. To improve data quality, the high resolution images on Google Earth provide another alternative for this project. The type and acquire date of the image have already been collected from Google Earth and only latest images or "clear" images were used. The footprints of high resolution images on Google Earth are shown in Figure 2. Four types of satellite image are used in this project over all –, Landsat ETM+, SPOT5, QuickBird, and GeoEye-1;. 23.4% glacial lakes are extracted from QuickBird and GeoEye; 30.7% glacial lakes are extracted from SPOT images and other 45.9% glacial lakes are extracted from Landsat ETM+.

Although all images are have been acquired after 2000 (Figure 3), but the acquire dates of the images vary from 2000 to 2010. Therefore, it's difficult to represent the glacial lake status in over a narrow period and can't be used as background data for glacial lake change analysis on a large scale.

Most glacial lakes are very small and can drastically change within years or even months. Many small lakes, especially periglacial lakes, can disappear and reform in a different image. Due to the limited data source, the seasonal changes of glacier lakes are difficult to capture with remote sensing data. The glacial lake from different images are required to be registered as much as possible in this project. Therefore, the small lake documented in this project just merely shows that mean there is a high probability of the formation of a waterbody in that landform (or depression).

The automatically method can speed up the process of glacial lake mapping, but the post process must be done by manually. The understanding to of glacial lakes is the one of main error sources of glacial lake inventory. The glacial lakes in this project are all documented by same person, and all of the lakes are were re-checked in the 3D environmental with the help of DEM. Therefore, the artificial error of glacial lake detection is low and shows uniform distribution overall. The main mistakes originate from the interference of low resolution, hill shade, snow cover, and cloud on satellite image. The area accuracy of glacial lake is impacted by the resolution of image;, the glacial lakes with area of 0.005km^2 from QuickBird and GeoEye satellite images are more trustworthy than the lake with area small than 0.05km^2 from Landsat ETM+ image.

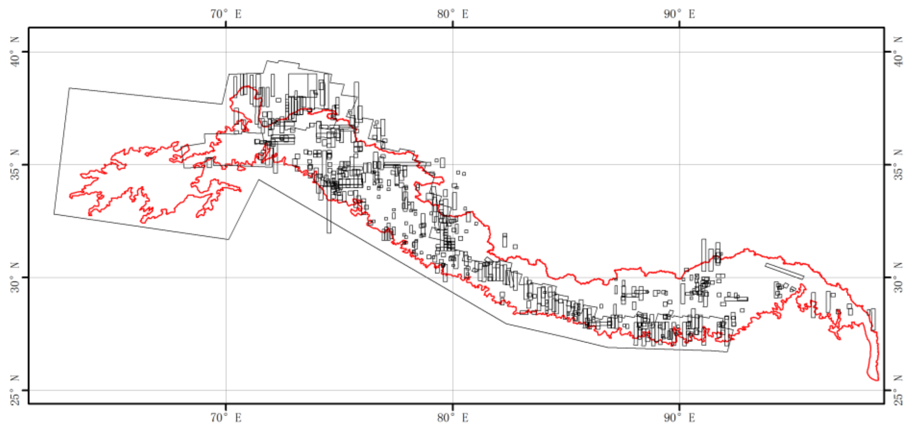

Figure 2: The footprint of high resolution images used

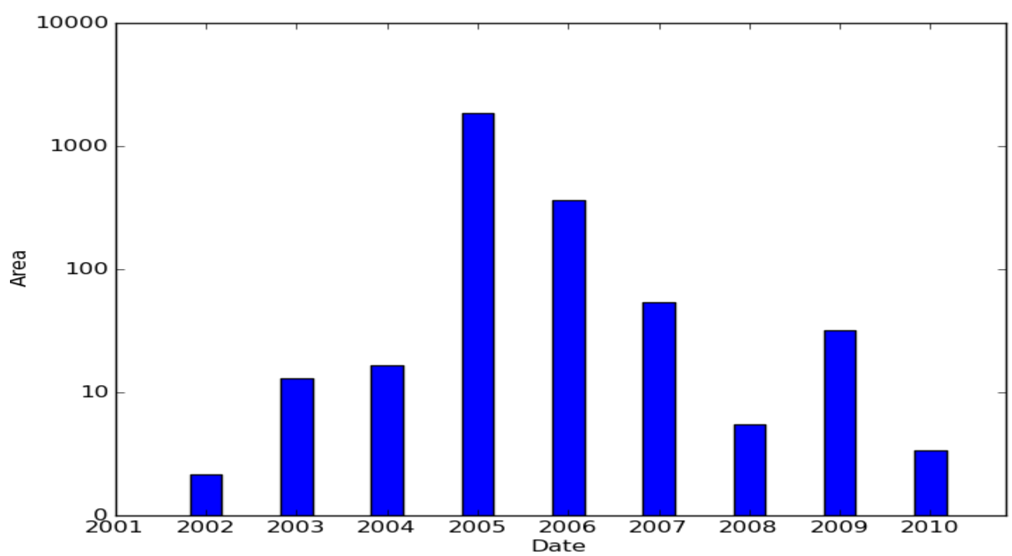

Figure 3: The date range of data source

Glacial Lake Classification

Based on the existing glacial lake classifications, new classification is are divided into four main types: glacial erosion (bed rock) lake, moraine dammed lake, ice dammed lake, and other lakes, as shown in Table 1.

Table 1. Glacial lake classifications used in the present study

S.N.	Glacial lake type	Code	Remarks
1	Glacier Erosion (Bed Rockbed rock) Lake (E)	E	
1.1	Cirque Lake	E(c)	
1.2	Other Glacier Erosion Lake	E(o)	
2	Moraine Dammed Lake	M	
2.1	End Moraine Dammed Lake	M(e)	
2.2	Lateral Moraine Dammed Lake	M(l)	
2.3	Other Moraine Dammed Lake	M(o)	
3	Ice Dammed Lake	I	
3.1	Supra Glacial Lake	I(s)	
3.2	Ice Dammed Lake	I(d)	
3.3	Lake Dammed by Glacier with Lateral Moraine	I(m)	
3.4	Other Ice Ddammed Lake	I(o)	
4	Non Glacial Dammed Lake	N	
4.1	Lake dammed by landslide, rock avalanche or debris	N(l)	
4.2	Artificial Lake	N(a)	
4.3	Other Non-glacial lake	N(o)	

Results

To date, 20,485 lakes have been registered in this project. Among these lakes, 20,204 lakes are glacial lakes, and 296 lakes are non-glacial lakes. The distribution map of glacial lakes is shown in Figure 4; the general statistics data are shown in Table 2. The glacial lake appears has different characteristics with from the difference glacial lake type.

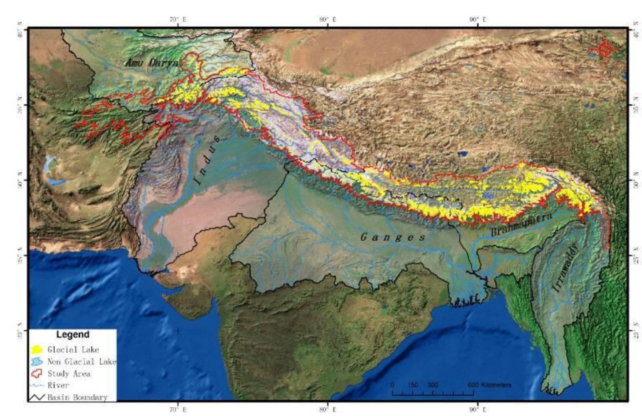

Figure 4: Distribution map of lakes of HKH region

Table 2: Glacial Lake in HKH region

Main Type		Sub Type	Code	Lake Number N	Lake Number %	Total Area (km^2) Area	Total Area (km^2) %	Mean Area (km^2)	Max Area (km^2)	Min Area (km^2)	Range of altitude
Glacial lake	Glacial erosion lake	Cirque lake	E(c)	1799	8.8	178.93	4.1	0.1	5.66	0.01	
		Other erosion lake	E(o)	608	3	726.47	16.8	1.19	291.45	0.01	
		Total	E	2407	11.8	905.4	21	0.38	291.45	0.01	
	Moraine dammed lake	End moraine dammed lake	M(e)	5134	25.1	741.35	17.2	0.14	39.18	0.01	
		Lateral moraine dammed lake	M(l)	131	0.6	20.12	0.5	0.15	2.28	0.01	
		Other moraine dammed lake	M(o)	10679	52.1	272.34	6.3	0.03	2.63	0.01	
		Total	M	15944	77.8	1033.81	23.9	0.06	39.18	0.01	
	Ice dammed lake	Supra-glacial Lake	I(s)	1765	8.6	10.31	0.2	0.01	0.26	0.01	
		Ice dammed lake	I(d)	21	0.1	1.5	0	0.07	0.7	0.01	
		Lateral moraine with ice dammed lake	I(m)	67	0.3	4.73	0.1	0.07	0.58	0.01	
		Other ice dammed lake	I(o)	0	0						
		Total	I	1853	9	16.54	0.4	0.01	0.7	0.01	
	Total of Glacial Lakes			20204	98.6	1955.75	42.25	0.1	291.45	0.01	
Non-glacial lake		Lake dammed by landslide, rock avalanche or debris	N(l)	157	0.8	62.09	1.4	0.4	6.91	0.01	
		Artificial lake	N(a)	61	0.3	33.74	0.8	0.55	22.71	0.01	
		Other non-glacial lake	N(o)	63	0.3	2268.82	52.5	36.01	625.3	0.01	
		Total	N	281	1.4	2364.65	54.7	8.42	625.3	0.01	
	Total			20485	100	4320.39	100	0.21	625.3	0.01	

References

Bhagat, R. M., B. Kalia, C. Sood, P. K. Mool, and S. R. Bajracharya, 2004, Inventory of Glaciers and Glacial Lakes and the Indentification of Potential Glacial Lake Outburst Floods(GLOFs) Affected by Global Warming in the Mountains of Himalayan Region, Himachal Pradesh, India Himalaya, ICIMOD.

Clague, J. J., and S. G. Evans, 2000, A review of catastrophic drainage of moraine-dammed lakes in British Columbia: Quaternary Science Reviews, p. 17-18.

Frauenfelder, R., B. Schneider, and A. Kääb, 2008, Using dynamic modelling to simulate the distribution of rockglaciers: Geomorphology, p. 130-143.

Huggel, C., 1998, Periglaciale Seen im Luft-und Satellitenbild, University of Zurich.

Huggel, C., A. Kääb, W. Haeberli, P. Teysseire, and F. Paul, 2002, Remote sensing based assessment of hazards from glacier lake outburst: a case study in the Swiss Alps: Can. Geotech. J., v. 39, p. 316-330.

Huggel, C., A. Kääb, and N. Salzmann, 2006, Evaluation of QuickBird and Ikonos Imagery for Assessment of High-Mountain Hazards, EARSeL eProceedings 5, 1/2006, p. 51-62.

ICIMOD, 2010, Hindu Kush-Himalayan Region.

Ives, J. D., 1986, Glacial Lake Outburst Floods and Risk Engineering in the Himalaya: Kathmandu, ICIMOD, 42 p.

Kääb, A., 2000, Photogrammetry for early recognition of high mountain hazards: new techniques and applications.: Physics and Chemistry of the Earth, v. 25, p. 765–770.

Liu, C., and C. K. Sharma, 1988, Report on the first expedition to glaciers and glacier lake in the Pumqu (Arun) and Poiqu (Bhote - Sun Kosi) River Basins, Xizang (Tibet): Beijing, Science Press, 192 p.

Mool, P. K., D. Wangda, S. R. Bajracharya, S. P. Joshi, K. Kunzang, and D. R. Gurung, 2001, Inventory of glaciers, glacial lakes, and glacial lake outburst flood monitoring and early warning system in the Hindu Kush-Himalayan Region, Bhutan: Kathmandu, Nepal, ICIMOD, 227 p.

Mool, P. K., S. R. Bajracharya, and S. P. Joshi, 2001, Inventory of glaciers, glacial lakes, and glacial lake outburst flood monitoring and early warning system in the Hindu Kush-Himalayan Region, Nepal: Kathmandu, Nepal, ICIMOD, 364 p.

Mool, P. K., and S. R. Bajracharya, 2003, Inventory of Glaciers and Glacial Lakes and the Identification of Potential Glacial Lake Outburst Floods(GLOFs) Affected by Global Warming in the Mountains of Himalayan Region, Tista Basin, Sikkim Himalaya, Kathmandu, ICIMOD.

Paul, F., C. Huggel, A. Kääb, T. Kellenberger, and M. Maisch, 2002, Comparison of TM-Derived Glacier Area with Higher Resolution Data Sets, Proceedings of EARSeL-LISSIG-Workshop Observing our Cryosphere from Space, Bern, p. 15-21.

Roohi, R., A. Ashraf, R. Naz, S. A. Hussain, M. H. Chaudhry, P. K. Mool, S. R. Bajracharya, B. Shrestha, and S. P. Joshi, 2005, Inventory Of Glaciers and Glacial Lakes and Identification of Potential Glacial Lake Outburst Floods(GLOFs) Affected by Global Warming in the Mountains of Himalayan Region, Indus Basin, Pakistan Himalaya, Kathmandu, ICIMOD.

Sah, M., G. Philip, P. Mool, S. R. Bajracharya, and B. Shrestha, 2005, Inventory of Glaciers and Glacial Lakes and the Indentification of Potential Glacial Lake Outburst Floods(GLOFs) Affected by Global Warming in the Mountains of Himalayan Region, Uttaranchal Himalaya, India, Wadia Institute of Himalayan Geology.

WECS, 1987, Study of Glacier Lake Outburst Floods in the Nepal Himalayas, Phase I, Interim Report, Kathmandu, Nepal.

Wu, L., T. Che, R. Jin, X. Li, T. Gong, Y. Xie, P. K. Mool, and S. R. Bajracharya, 2003, Inventory of Glaciers and Glacial lakes and the Indentification of Potential Glacial Lake Outburst Floods(GLOFs) Affect by Global Warning in the Mountains of Himalayan Region, Pumqu Basin, Tibet Autonomous Region of PR China, Lanzhou, Cold and Arid Region Environmental and Engineering Research Institute, p. 149.

Yamada, T., 1998, Glacier lake and its outburst flood in the Nepal Himalaya, Tokyo, Data Center for Glacier Research, Japanese Society of Snow and Ice.

Imja Lake Expedition Agenda

THE MOUNTAIN INSTITUTE

Adapting to a Changing Mountain World

Detailed Workshop Agenda

Imja Lake Expedition: 3-23 September, 2011

Day	Main Activity	Secondary Activities
September 3	**Participants arrive in Nepal**	Airport pickup, welcome, check into the Tibet Hotel, 7:00 p.m. dinner at the Nepali Chulo, Lazimpat
September 4	Preparations/logistics/purchase last minute trekking items	Invitation from ICIMOD to attend lecture by Dr. Patchouli, UNFCC Climate Change group
September 5	Fly to Lukla (2840 m) early morning, trek to Monjo (2835)(5 hours); Overnight at the **Summit Lodge**, Monjo	
September 6	Trek to Namche Bazaar (3440 m) (2-3 hours); Overnight at the **Khumbu Lodge**	Welcome to the Sagarmatha (Mt. Everest) National Park! **Evening presentations:** Pravin Maskey - Glacier recession impacts in Nepal; John Furlow – History and Future of South-South Workshops
September 7	Acclimatization day ("climb high, sleep low"); overnight at the **Khumbu Lodge**	Circuit trek from Namche Bazaar to Khumjung (3780 m) to Kunde 3840 m) and back; optional visit to Khumjung monastery **Field presentation:** Alton Byers - on glacial, vegetation, and cultural history of the region. **Evening presentations:** Ang Rita Sherpa, APPA Method of Planning

September 8	Trek to Tengboche (3860 m) (5-6 hours); overnight at the **Hotel Himalayan**	Visit to the Tengboche monastery; wildlife viewing; visit nearby landfill and discuss solid waste disposal problems in remote and popular national parks; **Evening presentations:** Jorge Recharte, Peaks to Coast
September 9	Trek to Dingboche (4410 m)(4 hours); overnight at the **Khumbu Resort**	Optional split into two groups, one taking the high trail through the fir-birch-rhododendron forest and across the Imja river to Pangboche; the other taking the traditional route through the village of Debouche. Lunch at the **Mountain Guide Lodge**, then continue on to Dingboche; **Evening presentations:** Cesar Portocarrero, Peruvian Glacial Safety Systems;
September 10	Acclimatization day in Dingboche; overnight at the **Khumbu Resort**	Optional trek to 5100 m viewpoint and back (4 hours); visit the Khumbu Alpine Conservation Council (KACC) headquarters and visitor center across from the hotel. **Evening presentations:** Julio Postigo, Adaptation in High Altitude Mattias Borg, Anticipation
September 11	Trek to Chukkung (4730 m)(2.5 hours); overnight at the **Chukung Resort**	**Evening presentations:** Ang Rita Sherpa, Khumbu Alpine Conservation Council and story of the Alpine Conservation Partnership. Dirk Hoffmann, Glacial recession impacts in Bolivia
September 12	Trek to Imja Lake (4830 m)(4 hours); establish **tented camp** south of the Imja Lake terminal moraine.	Settle in at basecamp (5100 m) **Evening discussion:** Collaborative research projects – Himalaya
September 13	Survey of Imja Lake (4830 m); trek toward Island Peak basecamp and ascend northernmost lateral moraine of Imja Lake ; overnight in **tented camp**	**Field presentation:** Teiji - Field presentations on history of the lake's development, risk factors, proposed mitigation strategies, applicability of Andean technologies to the HHK context **Evening discussion:** Collaborative research projects –

		Central Asia
September 14	Continued survey and study of Imja Lake (4830 m); optional trek to the Island Peak basecamp and beyond to visit the upper part of the receding Imja and Lhotse Shar glaciers; overnight in **tented camp**	**Evening discussion:** Collaborative research projects – Andes
September 15	Trek to Dingboche (4410 m)(3 hours); overnight at **Khumbu Resort**	**Evening presentations;** Lizong Wu, Glacier recession impacts in China Sonam Lhamo, Glacier recession impacts in Bhutan;
September 16	Trek to Lobuche (4910 m) (3 hours); overnight at the **Himalayan Eco Resort**	**Evening presentations:** Amjad Masood, Glacier recession impacts in Pakistan
September 17	Trek to Gorak Shep (5140 m) (2.5 hours) and Trek to Everest Basecamp (5364 m); overnight at **Himalaya Hotel**	Visit the Italian Ev-K2-CNR Pyramid Research Centre 15 minutes north of Lobuche enroute to Gorak Shep;
September 18	Trek to Kala Patar (5550 m) for best views of Mt. Everest, Nuptse, Lhotse, and surrounding snow peaks and glaciers or Trek to Everest Basecamp (5364 m); Trek to Lobuche (4910 m) (3 hours); overnight at the **Himalayan Eco Resort**	Visit the Italian Ev-K2-CNR Pyramid Research Centre
September 19	Trek to Pheriche (4410 m) (4 hours); overnight at **Resort**	**Evening presentations:** Mustaffar Shodmonov, Glacier Lake Assessment in Tajikistan Rodney Garrard, Landscape Change in the Khumbu Region
September 20	Trek to Deboche, Overnight at **Rivendell Resort**	**Evening presentations:** Bryan Mark, Impacts of glacial recession on regional water supply, Jeff Bury, Impacts of glacial recession on regional water supply;
September 21	Trek to Namche Bazaar (3440 m) (6 hours); Overnight at the **Khumbu Lodge**	**Evening presentations:** Maxim Petrov, Glacier Recession in Uzbekistan
September 22	Trek to Lukla (2840 m)(5 hours); Overnight at the **Northface Lodge**	**Evening presentations:** Adam French, Water Management in the Rio Santa, Peru Jeff La Frenierre, Topic TBD

September 23	Fly to Kathmandu early morning; check into **Summit Hotel** (closer to ICIMOD)	**Evening presentations:** Vladimir Shatravin, Debris Covered Glaciers in Kyrgyz Republic Marcelo Somos and Daene McKinney, GLOF Modeling of Palcacocha Lake, Peru
September 24	Rest day in Kathmandu	

Kathmandu Conference and Writers Workshop Agenda

Agenda An Adaptation Partnership Workshop: Andean-Asian Mountains Global Knowledge Exchange On Glaciers, Glacial lakes, Water & Hazard Management 25-26 September 2011	
Day 1 -- Sunday 25 September, 2011	
Time	Programme
8:15	Bus depart from Summit Hotel (guests at Greenwich walk to Summit parking area)
8:30	Registration at ICIMOD
9:00-10:20	Opening session - Welcome remarks by Andreas Schild, DG ICIMOD - Welcome remarks by Brian Peniston, TMI - Welcome remarks by John Furlow, USAID - Overview of the workshop and Introductions by Daan Boom
10:20-10:50	**Keynote Presentation** by Alton Byers, TMI: Andean-Asian Collaboration & Exchange for Enhanced Glacier Lake Control and Management
Session 1	**State of Knowledge of Glaciers, Glacial Lakes, and Hazard Management in the Andean – Asian Regions** (Chair: Daene McKinney, University of Texas at Austin; Rapporteur: Mrs. Susan Sellars and Aneeta Gaucham; Facilitator: Mrs. Miriam Lindwer)
10:50-11:10	Presentation by Bryan Mark, The Ohio State University: Global Overview of Glaciers and Contemporary Change
11:10-11:30	---------Tea/Coffee Break-------
11:30-11:50	Presentation by Teiji Watanabe, Dep. Of Geography, Hokkaido University, Japan: State of knowledge of Imja lake
11:50-12:10	Presentation by Ornella Puschasis, University of Paris: Overview of Local Perspectives on Water and Water Management in the Khumbu area, Nepal
12:10-12:30	Pradeep Mool, ICIMOD: Glacial lakes and GLOFs in the HKH
12:30-12:50	Presentation by Shodmonov Muzaffar, State Agency for Hydrometeorology, Tajekistan: State of Glaciers in Central Asia
12:50-13:15	Plenary Discussion with Q & A and Comments from the Speakers
13:15-14:00	Group Photo followed by lunch (ICIMOD Cafeteria)
Session 2	**State of Knowledge of Glacial Lake Management and Control in the Andean – Asian Regions** (Chair, Daan Boom and Pradeep Mool. Rapporteur: Mrs. Susan Sellars and Aneeta Gaucham; Facilitator: Mrs. Miriam Lindwer)

14:00-14:20	Presentation by Jorge Recharte, TMI: Building Community Capacity to Cope with Glacier Recession and Changing Water Supplies in the Cordillera Blanca, Peru
14:20-14:40	Presentation by Cesar Portocarrero, Glaciological Unit, Peru: 50 years of Experience in the Control and Management of Glacial Lakes in the Cordillera Blanca, Peru
14:40-15:00	Presentation by Arun Shrestha: Positive and Negative Aspects of Tsho Rolpa GLOF Risk Reduction Activities and Lessons Learned
15:00-15:20	Presentation Lizong Wu, Cold and Arid Region Environmental and Engineering Research Institute, China Academy of Science: Glacier Lakes and Their Changes in the HKH Region
15:20-15:50	Tea break/refreshments
15:50-16:10	Presentation by Dirk Hoffman: Glacial lakes and GLOFs in Bolivia
16:10-16:30	Presentation by Sonam Lhamo, Department of Geology and Mines, Bhutan: Glacial Lake Management in Bhutan
16:30-17:00	Plenary Discussion with Q & A and Comments from the Speakers
18.30> Reception dinner at Summit Hotel, Kupondole	
Day 2 -- Monday 26 September, 2011. Bus depart 8.30!	
Time	Program
Session 3	**Theme: Tools and Methods for Enhanced Glacial Lake Management and Control in the Andean – Asian Regions** (Chair: Prof Hua, ICIMOD; Rapporteur: Mrs. Susan Sellars and Aneeta Gaucham; Facilitator: Mrs. Miriam Lindwer)
9:00-9:20	Presentation by Glen Anderson, IRG and Daene McKinney, University of Texas at Austin: Vulnerability and Adaptation Approach to Climate Change Impacts
9:20-9:40	Presentation by Mandira Shrestha, ICIMOD: Flood Risk Reduction in the HKH
9:40-10:00	Presentation by Cesar Portocarrero, Glaciological Unit, Peru: Risk Assessment and Vulnerability Analysis of Dangerous Lakes in Mountain Areas
10:00-10:20	Presentation by Jeff Bury, University of California, Santa Cruz: Improvements to Glacial Lakes Safety Systems in the Cordillera Blanca, Peru
10:20-10:40	Presentation by Brian Peniston, TMI: Climate Change Adaptation Tools
10:40-11:00	Presentation by Birendra Bajracharya, ICIMOD: SERVIR Himalaya, Regional Data Sharing and of snow, ice and glaciers
11:00-11:30	---------Tea/Coffee Break--------
11:30-11:50	Presentation by Dhrupad Choudhury, ICIMOD: Climate Change Adaptation and Livelihoods Resilience in the HKH region
11:50-12:10	Presentation by Julio Postigo, University of Texas at Austin: Local Responses to Climate Change in the Quelcaya Region, Peru
12:10-12:30	Plenary Discussion with Q & A and Comments from the Speakers
12:30-13:00	Jorge Recharte, TMI: Guidelines for Afternoon Breakout Groups
13:00-14:00	Lunch (ICIMOD cafeteria)
Session 4	*Working Group Discussions on Workshop Recommendations*
14:00-15:15	- 3 groups to be divided by theme (Sessions 1-3)

	- Working Group Leaders: o Working Group 1 (Glacial Lake Knowledge): Bryan Mark (rapporteur Aneeta Gaucham) o Working Group 2 (Glacial Lake Management): Daan Boom (rapporteur TMI) o Working Group 3 (Tools and methods for Lake Management): Katalyn Voss (rapporteur Ujol Scherchan) Group discussions - Discussions focused on key recommendation on each theme of the workshop - Group Leaders prepare summary presentations for Session 5 with inputs from group members
Session 5	Working Group Presentations and Discussion
15:15-16:45	Presentation by the 3 Group Leaders and discussion; Facilitator: Mrs. Miriam Lindwer - 3 Group Leaders to present Working Group recommendations - Discussion of the recommendations and next steps
16:45-17:00	Closing Remarks - Madhav Karki, ICIMOD - Alton Byers, TMI

Agenda Writers Workshop 27-28 September 2011	
Day 1-- Tuesday 27 September, 2011	
Time	Program Facilitator: Susan Sellars
9:00-10.00	Discussion of Workshop Objectives and Outputs, Glen Anderson, IRG
10:00-11.30	Working Group Discussions on Workshop Proceedings
	Objective: Capture and publish the proceedings and other outputs that emerge from both the Imja Lake Field Expedition and follow-on workshop in Kathmandu Instructions to Working Groups: Develop an outline for the proceedings of each theme: (1) Glaciers, Glacial Lakes, and Water Supply in the Andean – Asian Regions, (2) Glacial Lake Management and Control in the Andean – Asian Regions, and (3) Tools and Methods for Enhanced Glacial Lake Management and Control in the Andean – Asian Regions Group discussions with Working Group Leaders:

	- Working Group 1 (Glacial Lake Knowledge): Bryan Mark - Working Group 2 (Glacial Lake Management): Daan Boom - Working Group 3 (Tools for Glacial Lake Management): Katalyn Voss
11:30-12.30	Working Group Reports
	Presentation by the 3 Group Leaders and discussion - 3 Group Leaders present Working Group progress - Discussion
12:30 – 13:30	Lunch
13:30 – 16:00	Working Group Discussions on Priority Research and Action Projects
	Objectives: Capture recommendations for priority research and action projects Instructions to Working Groups: Develop a list of priority research and action pilot project needs in the HKH-Andes-Central Asian regions: Group discussions with Working Group Leaders: - Working Group 1 (Glacial Lake Knowledge): Bryan Mark - Working Group 2 (Glacial Lake Management): Daan Boom - Working Group 3 (Tools for Glacial Lake Management): Katalyn Voss
16:00-17.00	Working Group Reports
	Presentation by the 3 Group Leaders and discussion - 3 Group Leaders present Working Group progress - Discussion
	Day 2—Wednesday 28 September, 2011
Time	Program
9:00 – 10:00	Summary of First Day Results, Alton Byers and Daene McKinney
10:00 – 11:30	Partnerships and Funding Opportunities
	Objectives: Capture recommendations for partnerships and funding opportunities Instructions to Working Groups: Develop a list of partnerships and funding opportunities in the HKH-Andes-Central Asian regions: Group discussions with Working Group Leaders: - Working Group 1 (Glacial Lake Knowledge): Bryan Mark - Working Group 2 (Glacial Lake Management): Daan Boom - Working Group 3 (Tools for Glacial Lake Management): Katalyn Voss
11:30-12.30	Working Group Reports
	Presentation by the 3 Group Leaders and discussion - 3 Group Leaders present Working Group progress

	- Discussion
12:30-13.00	Wrap-up of Writers Workshop
13:00 – 14:00	Lunch

Participant List for "An Adaptation Partnership Workshop: Andean-Asian Mountains Global Knowledge Exchange"

MW: Mobile Workshop (Imja Glacial Lake Field Expedition)

KW: Kathmandu Workshop

WW: Writers Workshop

TMI: TMI-funded

X: Attending

I. TMI-affiliated and/or supported Participants

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10	Ing. Jesus Gomez	Glaciological and Hydrological Resources Unit, Glaciologist	Peru	x	x	x	x
11	Ing. Alejo Cochachin	Glaciological and Hydrological Resources Unit, Glaciologist	Peru	x	x	x	x
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16	Brendan Hickey	Social Media Specialist, brendan.m.hickey@gmail.com	US	x		x	
17	James McKinney	Wilderness EMT and medical student	US	x	x	x	
18	Mattias Borg Rasmussen	Department of Anthropology, University of Copenhagen, Telephone +45 35 32 43 76	Denmark	x	x	x	
19	Karsten Pærregaard	Meteorologist, Copenhagen University, Denmark, rasulpmd@gmail.com	Denmark		x	x	
20	Jorge Recharte	Director, Instituto de Montaña, The Mountain Institute, jrecharte@mountain.org		x	x	x	x
21	Maxim Petrov	glacio-geomorphologist and geologist, State Agency for Hydrometeorology, maxpetr1962@gmail.com	Uzbekist an	x	x	x	x
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23	Nasimjon Rajabov	Hydrology/glaciology specialist, State Agency for Hydrometeorology, anvar.homidov@gmail.com	Tajikista n	x	x	x	x
24	Shodmonov Tursunovich Muzaffar	Climatology/glaciology specialist, State Agency for Hydrometeorology, mshodmonov@gmail.com,	Tajikista n	x	x	x	x
26	Kate Voss	The Mountain Institute	US	x	x	x	x
27	Ruth Bell	The Mountain Institute	US		x	x	
28	Lisa Friedman	Journalist, ClimateWire	US	x	x	x	
29	Glen Anderson	IRG, USA	US	x	x	x	
30	Sonam Lhamo, Geologist	Glaciology Division, Department of Geology and Mines, Royal Government of Bhutan,Thimphu, Bhutan	Bhutan	x	x	x	x
31	Pravin Raj Maksey	Ministry of Irrigation, Nepal, Irrigation Engineer, prmaskey@gmail.com	Nepal	x	x	x	x
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33	Ghazanfar Ali	Global Change Impact Studies Centre (GCISC), Saudi-Pak Tower (First Floor),61/A Jinnah Avenue, Islamabad. Glaciologist	Pakistan		x	x	x
34	Amjad Masood	Engineer, GCISC, NCP Complex, Near Quaid-i-Azam University, Shahdara Road,	Pakistan	x	x	x	x

		Pakistan					
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37	Netra Sharma (Sapkota)	NRM and GCC Team, General Development Office, USAID Nepal	Nepal		x		
38	Suzanne Goldenberg	Journalist, UK Guardian	US	x			
39	Ang Rita Sherpa	Senior Program Officer, The Mountain Institute,angrita@mountain.org	Nepal	x			x
40	Stephanie Spray	Fulbright Scholar, sspray@fas.harvard.edu	US	x	x	x	

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44	Dhananjay Regmi	Tribhuvan University, Department of Geography, Glaciologist, dj.regmi@gmail.com	Nepal		x	x	
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47	Niaz Ali	Glaciologist, Focus Humanitarian Assistance, Islamabad, Pakistan,	Pakistan		x	x	

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50	Jenty Kirsch -Wood	UNDP, Nepal	Nepal		x		
51	Anupa Rimal Lamichhane	UNDP, Nepal	Nepal		x		
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65	Susan Sellars	ICIMOD	Nepal		x		
66	Pasang Yangjee Sherpa	ICIMOD	Nepal		x		
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Annex 1: Media Scrapbook

THE MOUNTAIN INSTITUTE

Expedition Clip Book: Imja Lake Region, Nepal

September 3- 23, 2011

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theguardian

Sept. 2, 2011, The Guardian, Suzanne Goldenberg

Follow my expedition into the new landscapes of the Himalayas

Travelling with the Mountain Institute, I will visit Lake Imja on foot, learning about its development, and its potential risks

Starting from the western face of Kali Himal, the Imja Glacier flows through eastern Nepal, part of a glacier network that ultimately feeds the Ganges. Photograph: Nasa

Short of a trip to the north pole, there is probably no better place to view – right now, not at some distant point in mid-century – how climate change is carving out new landscapes than in the Himalayas.

The mountains, which contain more than 100 peaks above 7,000m, are the largest repository of ice outside the poles. The very name Himalaya means "abode of snow" in Sanskrit. Unlike the Arctic, though, there are hundreds of millions of people who depend on this landscape to remain as it is.

Come spring, the season melt from high-altitude glaciers swell the Ganges and the Brahmaputra, the Irrawaddy and the Yangtze, providing water to farmers and cities.
But the glaciers are slowly disappearing, especially those at lower altitudes, and which fall under the influence of the summer monsoons – such as many of those in the Everest region of eastern Nepal.

I'm going to be travelling through that area – mostly on foot – on an expedition led by the Mountain Institute, a US-based organisation which works to preserve mountain environments from the Andes to the Appalachians and beyond.

The Mountain Institute has assembled a group of international scientists and other experts from the US, Latin America, Europe and Asia to take a first-hand look at climate change in the region, and to try to come up with remedies for local people.

The focus – and the destination of the 18-day journey – is Lake Imja. The lake, billed as the highest in the world, did not exist before the early 1960s. But over the years water from the melting Imja glacier began pooling behind a natural dam. The lake now measures 2.5km long.

Glacier lakes, which are occurring across Nepal and Bhutan, are one of the biggest dangers of climate change in the region. When such lakes burst – and they do – they can cause catastrophic floods downstream.

The objective of the Mountain Institute on this trip is to develop safeguards against such floods and, possibly, ways local people can benefit from their new lake. There is a large contingent on the trip from Peru, where they have been dealing with glacier lakes since the 1940s – sometimes even developing them as sources of hydropower.

It's exciting new territory. The Himalayas, because of their sheer vastness, are the least understood mountain range on the planet.

That knowledge gap became painfully obvious two years ago during the controversy over the false claim in the IPCC report that the Himalayan glaciers would melt into oblivion by 2035.

Glacier experts who work in the Himalayas say they knew instantly the claim in the 2007 report was wrong, but it took two years before the IPCC officially admitted the error, damaging the public image of climate scientists.

Since then, scientists have been working hard to fill those knowledge gaps – with satellite imagery, aerial photographs, or like the Mountain Institute, a long climb up to the peaks.

We will start by flying to Lukla, a town situated at about 9,383ft in the Everest region of eastern Nepal. I'm told the descent feels like you are going to smash right into the side of a mountain.

From there it should take two days to reach the town of Namche Bazaar. It's the largest town in the region – which is not saying much – it had a population of under 2,000 during the last census 10 years ago – and a centre of Sherpa and trekking culture. It's at an altitude of 11,286ft 27°49′N 86°43′E. Then we will start making our way towards Imja Lake, 27.898°N 86.928°E

Our route is a well-known one for those familiar with the Everest region. We won't be moving fast – it's important to build rest days into the schedule to acclimatise to the high altitude. And we will be stopping en route to Imja, at the village of Tengboche, 27°50′01″N 86°41′59.85″E where there is an important Tibetan Buddhist monastery and again at the villages of Dingboche. 27°53′N 86°49′E and Chukkung 27°54′18″N 86°52′17″E.

The plan is to spend three nights at Imja, learning about its development, and its potential risks. Could a sudden rock fall cause a catastrophic flood, with waters cascading down on the villagers below? Or, is there a way the lake can benefit local people?

We will be retracing our footsteps on the way back, except for a diversion to get a closer view of Everest and climb up to base camp 28°0′26″N 86°51′34″E) at nearly 18,000ft.

I'll hope you will follow me here or on Twitter, especially those who have been there before me. You can also follow the journey on the Mountain Institute's blog.

theguardian

Sept. 7, 2011, The Guardian, Suzanne Goldenberg

Himalayas expedition scales the remote mountains to Namche

Two days into the trip and the great injustice of climate change is clear: countries least responsible for the problem will suffer most

Yaks haul goods on a trail in the Himalayas. Photograph: Prakash Mathema/AFP /Getty Images

It's just 10kms from Lukla – the airport that was part of Sir Edmund Hillary's thank you to the people of Nepal – to the main Sherpa town of Namche Bazaar.

But it's a solid two days' walk, with the last 2 miles a steep uphill climb up the mountains to Namche, which is at 3,440m or 11,286ft.

The scenery along the way is gorgeous, obviously: small villages with tidy plots of cabbages and beans, and bright busts of dahlias, and dramatic river crossings over bouncing wire bridges.

But the journey with the scientists from the Mountain Institute does drive home one of the great injustices of climate change: the countries least responsible for the problem are due to suffer the most.

Nepal consistently ranks among the poorest countries in the world. Even here, in the Everest region which is reputed to be relatively better off because of tourism revenue, living standards are low. Porters for these trekking trips earn about $15 a day.

In Nepal's case, the sheer remoteness of the Himalayas makes it even harder to monitor glacier loss, or devise strategies to protect future generations from the worst effects of climate change.

Lukla is almost completely surrounded by mountains and is only accessible to small aircraft. We flew in on a Twin Otter. The airport shuts down when there is cloud cover.

That makes it hard to schedule research trips and to fund them. It's hard to calculate costs for donors if you don't know how long you will be waiting around for a plane.

Namche Bazaar does have a helicopter pad, but for the most part the only way in, for scientists as for other travellers, is on foot from Lukla. The only way for those scientists to bring in necessary equipment is to carry it themselves, or hire human porters, and yak or horse caravans.

And these are both just gateway towns, after all. The glaciers and glacier lakes which are already showing the imprint of climate change are even more remote.

Consider the experience of Teiji Watanabe, an expert on glacier lakes from Hokkaido University who is on the expedition.

Watanabe has done considerable research on Imja Lake – the focus of this expedition. The lake, which did not exist half a century ago, is the fastest growing glacier lake in Nepal.

Though the lake seems stable for now, local people and the authorities are worried that it could one day burst its banks, engulfing villages and destroying hard-won infrastructure.

On one of his last trips, Watanabe brought in a boat so he could get depth readings from the lake. The boat, an inflatable rubber dinghy weighing about 50kg, had to be carried in by porter. Watanabe would have liked to bring in an engine as well to power the boat – but was told that would be too heavy and expensive to bring all the way up to Imja, which is about 5,000m. Watanabe ended up rowing the boat around the lake.

Pravin Raj Maskey who has joined the expedition from Nepal's ministry of irrigation, had better luck on one of his last trips to Imja.

He managed to get a boat and an engine all the way up to Imja – only to find out that the engine could not run at that altitutde, because there was not enough oxygen.

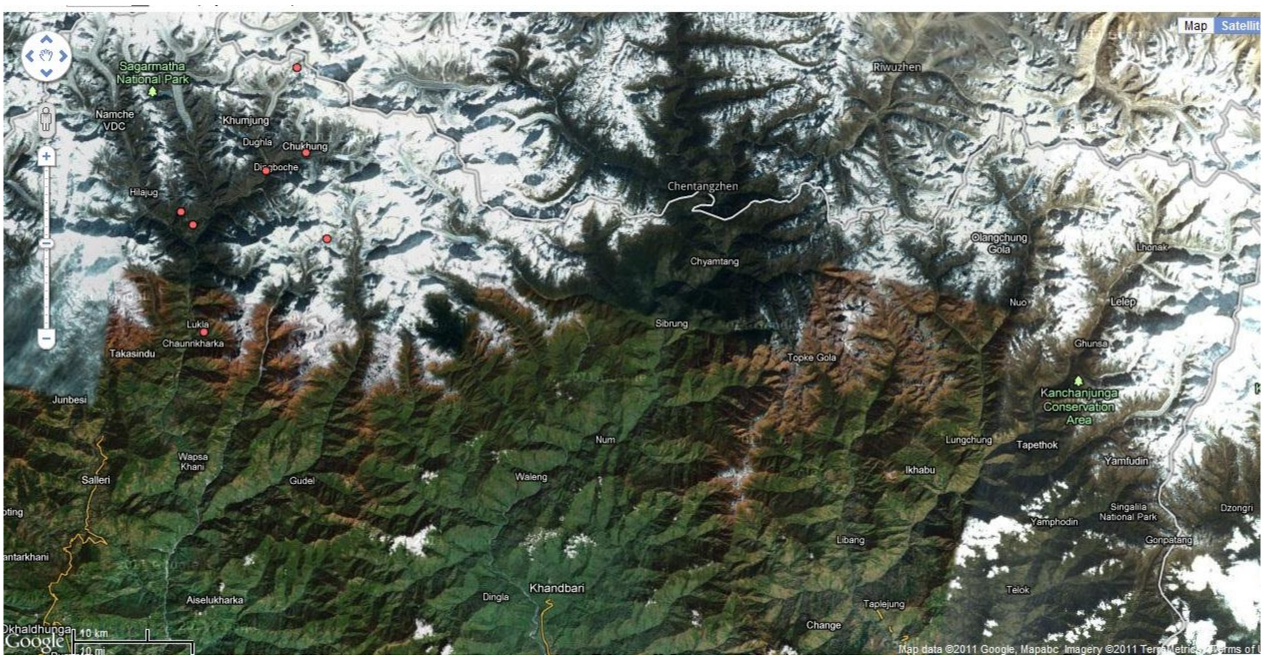
I'm planning to spend the next day or so around Namche to see what local people think about the changing glaciers, and those who come here to study them. From there, it's on to the town of Dingboche.

theguardian

Sept. 9, 2011, The Guardian, Suzanne Goldenberg

Suzanne Goldenberg's expedition in the Himalayas – map

Follow Suzanne Goldenberg's journey through the Himalayas as she documents the changing environment



View Full Map.

theguardian

Sept. 12, 2011, The Guardian, Suzanne Goldenberg

Himalayas in danger of becoming a giant rubbish dump

Nepal wants to lift itself out of poverty by expanding its tourism industry but there is no strategy for waste disposal

The trash dumpsite in the Khumbu. Photograph: Daniel Byers./Mountain Institute Expedition

There's nothing like waking up to bright clear skies with spectacular views of the Lhotse and Amu Dablam ranges – and a rubbish dump.

This heap of beer cans, mineral water bottles and other material was just a few minutes' walk outside the village of Tengboche. It represents about a season's rubbish.

The dump is not on the regular trekking trails which are, aside from the stray Fanta and instant noodle wrapper, admirably clean. And most trekkers have no idea of their impact on the remote Everest landscape, said Alton Byers, who is leading our expedition as director of the Mountain Institute.

But the dump exposes the risks of Nepal's strategy of lifting itself out of poverty by expanding its tourism industry. "At this altitude and in this environment, this [rubbish] will be here for 1,000 years," Byers said.

The government has declared 2011 Nepal tourism year, and has sought to double the number of visitors to 1 million. But can remote communities handle those numbers? Only a fraction of tourists to Nepal make it to the Everest region – about 31,000 last year.

But those numbers are already taxing local villages. In high season, which runs from mid-September through December, it can be hard to find a room on some of the trekking routes.

It's even harder to clean up after the trekkers once they are gone. "Thirty years ago, there was no garbage. There was no plastic," said Byers. Now, he said: "we see this in every village all the way up to Everest base camp."

Even the village of Namche Bazaar, the biggest in the region, does not have a waste treatment system. Sewage from the 45 lodges is dumped directly into a canal, which eventually feeds into the Khosi river, according to Orenlla Puschiasis, a researcher from the University of Paris West-Nanterre, who is working on water quality in the region.

"There is nothing sustainable about it," she said. "To be sustainable they have to think about the future and manage the waste and the sewage water."

Trekking companies are supposed to carry their rubbish out with them – but most do not. Lodge operators balk at the idea of paying to cart out beer cans by yak. And even if they do carry the rubbish down to Kathmandu, what then? There is no developed recycling industry in Nepal – not even in Kathmandu.

Maybe it's time for some waste treatment plants right in the Everest region.

theguardian

Sept. 14, 2011, The Guardian, Suzanne Goldenberg

Himalayas expedition finds evidence of 'disaster in the making'

The disappearance the juniper bushes, which hold the soil together, will cause problems, Mountain Institute scientists say

Dingboche village in foreground and Kang Taiga and Tramserku mountains. Photograph: Armands Pharyos/Alamy

After a day of trekking through rhododendron forests, the Mountain Institute expedition has now travelled above the tree-line to the village of Dingboche.

The village, which sits at about 4,400m, has a population of about 70 year-round, though it will grow considerably when the trekkers starting moving through in the next week or so.

This is one of the last staging posts before the Mountain Institute moves up to Imja Lake, the focus of the expedition.

The landscape has changed with each gain of elevation: through thick forests with butterflies and wildflowers of every description, slopes covered with rhodedendron, and now the higher terrain, which traditionally was covered with juniper.

The hill behind Dingboche is bare though. Much of the juniper has been cut down for firewood. Its disappearance is a disaster in the making, the scientists of the Mountain Institute say.

The juniper bushes are one of the few plants that can thrive at these heights, and that can help hold the soil together. On the trek up to Dingboche, several of the cliffs are scoured by recent landslides.

The bushes are extremely slow-growing, it could decades before the slope is covered again.

The demand for fuel didn't used to take such a toll on the local surroundings. But hundreds of tourists pass through Dingboche in the trekking season, and the lodges need the fuel to feed them.

Until a few years ago, villagers even used to chop down the juniper to send up to Everest base camp. The bushes were burned as offerings for a successful ascent.

Thankfully that practice has now stopped, and the Mountain Institute and other organisations have been working with local people to find ways to protect the juniper, and the hillsides.

There is no easy fix though. Kerosene is a more expensive cooking fuel. Solar is just too slow. A number of homes along our route have huge reflective solar dishes, which can be used to heat water for cooking or bathing. "It makes life easier sometimes," said Dilli Kumar Rai, who lives just outside the village of Tengoche. But she added, it still takes 45 minutes to make a cup of tea.

theguardian

Sept. 16, 2011, The Guardian, Suzanne Goldenberg

Watching a glacier die at Imja Lake

The Mountain Institute hopes it can assess the threat from Imja to villagers living below – and provide some solutions

Lake Imja in a valley situated south of Mount Everest in Nepal. Photograph: HO/AFP /Getty Images

It's an odd sensation to watch a glacier die, the snow sliding off the massive black cliffs, punctuated with the cracks of big ice blocks falling away. The Mountain Institute has been doing just that, the last couple of days, watching the scenes at Imja Lake.

Imja is the fastest-growing glacier lake in Nepal. The sheer fact of its existence is evidence of the increasing pace of climate change in the high mountains of the Himalayas. The glaciers are melting – although some undoubtedly will remain solid blocks of ice for hundreds more years – and they are spattering the high altitudes with glacier lakes like Imja.

The lake, a sludgy grey-green, stands at about 5,100 metres. It's a nine-day trek from the nearest airport at Lukla, and several days away from electricity or telephone services.

Even the Nepal government rarely ventures here. So bringing in 32 scientists from 13 countries, as the Mountain Institute has done, is a logistical nightmare.

Seventeen tents, 60kg of rice, a generator which turns out to be unreliable, and 6kg of yak cheese – it takes a lot to keep a large group going for three days.

There's been ice outside the tents some mornings. But on clear days, there are spectacular views of the Lhotse and Nupse mountains across the river bed.

The Mountain Institute is hoping the scientists will be able to assess the hazard from Imja to the villagers living below – and come up with some solutions.

It's been difficult to get a clear answer over the years on the likelihood of Imja one day breaking its banks, which are made of rock and debris piled over ice. By this point, however, the local people who have trekked up to the lake from nearby Dingboche say they are beyond caring what science has to say about the melting glaciers.

theguardian

Sept. 19, 2011, The Guardian, Suzanne Goldenberg

The sound of a glacier – Wind Horse by Stephanie Spray

The anthropology PhD candidate from Harvard describes the sound of a glacier as being 'like the belly of the Earth groaning'

Wind Horse by Stephanie Spray.

theguardian

Sept. 19. 2011, The Guardian, Suzanne Goldenberg

What does a glacier sound like?

An anthropologist from Harvard, who has made a collection of awe-inspiring sounds, says it is like 'the belly of the Earth groaning'

The Khumbu glacier at Everest-Khumbu region one of the longest glaciers in the world. Photograph: Subel Bhandari/AFP/Getty Images

Stephanie Spray, a PhD candidate in social anthropology from Harvard, has joined the Mountain Institute expedition with the hope of producing a sound installation of the people and landscapes along the way.

Spray, who has been visiting Nepal for 12 years, started on the project last year, with the original idea of tracking the Dudh Khosi river, up to its source in the glaciers.

By the time she had climbed into the Himalayas, however, Spray decided that the sounds of glaciers were more interesting, and she spent some time recording around the Khumbu glacier, near Everest.

So what does a glacier sound like? Spray said she captured a collection of sounds, from the sharp crack of falling ice to the gurgling sounds of trapped water.

"It sounds like the belly of the Earth groaning," said Spray. "I find it terrifying. That is part of the appeal to me. For me it restores a kind of awe to the environment."

Her earlier recording is called Blue Sky, White River, and you can listen to it below.

theguardian

Sept. 22, 2011, The Guardian, Suzanne Goldenberg

Himalayas earthquake brings home urgency of securing glacier lakes

With avalanches and mudslides, the quake was yet another reminder of the dangers of living in an unstable region

An aerial view of the 18 September earthquake-affected areas on the outskirts of Gangtok. Photograph: Sandesh Rokade/AFP/Getty Images

This week's earthquake in the Himalayas was another reminder of the dangers of living in an unstable region, as you might expect. This part of the Himalayas got off relatively lightly – as opposed to the epicentre of the quake in the Indian state of Sikkim.

Even so, it brought avalanches and mudslides, wiped out a strategic wire foot bridge near the town of Lukla, and damaged a number of homes.

For the Mountain Institute expedition, the quake brought home the urgency of securing glacier lakes such as Imja. The Mountain Institute is winding up its expedition, and will reconvene in a series of workshops in Kathmandu next week.

It is not immediately clear how – or even if – the earthquake destabilised the natural dams holding in Imja or any of the region's other newly formed glacier lakes. But the scientists and engineers are hoping the expedition will help develop new methods of dealing with climate hazards.

First: south-south co-operation. A main premise of the expedition is that Nepal can learn from the experience of Peru, which has been dealing with the problems of glacier lakes for decades – without foreign assistance.

That's a departure from the normal order where Nepal, one of the poorest countries in the world, typically looks to Europe or North America for disaster preparedness or development funding. This expedition is almost entirely funded by the US government, with contributions from the US Agency for International Development, the State Department, and the National Science Foundation.

But it is heavy on Andean expertise. César Portocarrero, head of the department of glaciology and water resources at the National Water Authority of Peru, had decades of experience in dealing with glacier lakes, before making the trek to Imja.

He has overseen engineering works on 35 lakes securing them against future collapse. "I think we can be proud that we created our own technology in Peru to work with these kinds of problems," he said. Portocarrero now hopes to suggest some of those solutions for Imja and other glacier lakes in Nepal.

The other underlining premise of the Mountain Institute's expedition is involving local people in decisions about glacier lakes.

As I've said earlier, local people are getting fed up with scientific expeditions to Imja. They say they want a final decision on whether the lake is safe – or could one day unleash a catatastrophic flood. And yes, they would like hydropower from the lake too.

But making yourself popular here is harder than might appear. Nepali studies suggest that a flood from Imja Lake could devastate up to 100km of farmland and infrastructure. So which local communities to involve?

As the Mountain Institute itself notes on its blog of the expedition:

> It is unclear right now who our best partners might be in the Imja Valley. There are village and district level committees; in some areas, committees of lodge owners are forming. But there is little or no coordination between the various constituents on many issues …
> There is the Sagarmatha (Mt Everest) National Park management. And there is the Nepali national government. A project of the scale of managing Imja Lake's flood risk calls for a big partner, not a village of a few dozen families and a handful of tourist lodges. However, the national government's influence in the Imja area is not evident — there are few schools and no post offices.

There is another issue the post fails to raise – gender. How to ensure that women and men have a say in community decisions.

On our first meeting with local people in the town of Dingboche, the women left the room, after singing a traditional welcome song and serving tea. None of the women participated in the discussion about what to do about the lake.

The delegation from the Mountain Institute did not set much of an example. Of the 32 scientists participating in the trek only one – a geologist for the government of Bhutan – is a woman. There are two other women on the trip: a PhD candidate in anthropology who is listed as a member of the social media team, and an intern at the Mountain Institute office in Kathmandu, also listed as a member of the social media team.

But it does suggest that ensuring adequate representation and inclusion are not solely a challenge for the developing world.

I'll be returning to these issues – and others – in the days ahead.

theguardian

Sept. 25, 2011, The Guardian, Suzanne Goldenberg

Everest's ice is retreating as climate change grips the Himalayas

Climate change is altering the face of the Himalayas but research seeking to confirm this is yet to catch up with the mountain communities sounding the alarm. After an 18-day trek with scientists, Suzanne Goldenberg finds the warning signs hard to ignore

Glacier AX010 in Shorong, Nepali Himalayas. AX has shrunk by 0.81 metres respectively per year in the 2000s, up from 0.68 and 0.72 metres per year between 1970 and 1990, according to Koji Fujita at the Graduate School of Environmental Studies in Nagoya University in Japan. Photograph: Koji Fujita/Nagoya University

The climb to Everest base camp is a journey into a monochrome world, a landscape reduced to rock, ice and grey sky. The only spots of colour are the bright, domed tents of the few climbing teams willing to attempt the summit in the off-season.

There are no birds, no trees, just the occasional chunks of glacier splashing into pools of pale green meltwater like ice cubes in some giant exotic drink. The stillness suggests nothing has changed for decades, but Tshering Tenzing Sherpa, who has been in charge of rubbish collection at base camp for the past few years, remains uneasy. "Everything is changing with the glaciers. All these crevasses have appeared in the ice. Before, base camp was flat, and it was easy to walk," he said.

Climbers had reported that they barely needed crampons for the climb, there was so much bare rock, Tenzing said. That's not how it was in Edmund Hillary's day. Tenzing pointed towards the Khumbu ice fall – the start of the climb, and part of a 16km stretch of ice that forms the largest glacier in Nepal. "Before, when you looked out, it was totally blue ice, and now it is black rock on top," he said. He's convinced the changes have occurred in months – not years, or even decades, but during the brief interval of the summer monsoon. "This year it's totally changed," he said.

This much is known: climate change exists, it is man-made, and it is causing many glaciers to melt across the Himalayas. Beyond that, however, much is unclear or downright confusing.

For that, scientists blame a blunder in a United Nations report that was presented as the final word on climate change. The 2007 report – which included the false claim that the Himalayan glaciers would disappear by 2035 – probably did more to set back science, and delay government action on climate change, than any other event. The scandal, known as Glaciergate or Himalayagate, was a gift to climate-change sceptics when it came to light early last year, and a deep embarrassment to glaciologists. Now they are desperately trying to recover.

Mention melting and Himalayas to almost any glacier expert working in the region, and they will instantly plead for caution: please do not repeat the mistake of thinking all the ice will be gone in the next few decades. "It was just nonsense," said Alton Byers, the scientific director of the Mountain Institute. "It's absolutely staggering when you look at some of those high mountains. They are frozen solid, at minus 15 or 20 degrees, and they are going to remain that way."

At lower elevations, it's a different scenario, Byers acknowledged. Low-lying glaciers are melting, and far more rapidly in the past 10 or 15 years than in previous decades, scouring out new landscapes and creating a whole new realm of natural disasters for countries that are some of the poorest on Earth.

I accompanied the Mountain Institute and 32 scientists and engineers from more than 13 countries on an expedition looking into some of the new hazards.

After flying to the Nepali town of Lukla – landing in an airport partly built by Edmund Hillary – the 18-day trek took us to Everest base camp and to Imja lake to look at a prime potential danger of climate change in the mountains: catastrophic, high-altitude floods. Melting ice turns to glacial lakes which grow in size until – one day – they risk rupturing their banks, spewing out rocks and debris. Such outbursts can kill, and they almost always invariably destroy infrastructure and land, burying fields in several metres of rubble.

That's seen as the biggest potential hazard. There are more than 1,600 glacial lakes in Nepal alone, of which about a half dozen are considered very dangerous. But glacier loss could also destabilise mountainsides or devastate water supplies. Some of Asia's mightiest rivers – the Indus, Ganges, Brahmaputra – depend to some extent on seasonal glacier melt. In Pakistan, the Indus river system derives between 60% and 80% of its flow from summer melt, according to Amjad Masood of Islamabad's Global Change Impact Studies Centre. In Uzbekistan, half of the rivers in the Tashkent area rely on water from glaciers, said Maxim Petrov, head of glaciology at the Academy of Sciences.

The problem is people who live with the mountains are already convinced their landscape is changing, and have given up on waiting for scientists to confirm it. Local people say they can see evidence of climate change everywhere: trees growing higher up mountain slopes, houseflies buzzing at 5,000m, monsoon rains arriving at inconvenient times.

Some see the hand of divine retribution. Kancha Sherpa, the sole surviving member of Hillary's expedition, believes the melting glaciers are a punishment for defiling nature. Now 79, he spends his time in the main town of Namche Bazaar in a room painted pale pink and lined with pictures of past expeditions. "I believe the gods reside in the mountain, and now with all the mountains being climbed they have been polluted. I believe God is not happy with all the people climbing in the hundreds."

Birendra Kandel, a conservation officer at the Sagamartha national park, which includes Everest, argues that animals are already roaming beyond their typical ranges. A few years ago, on a field trip, he spotted a common leopard prowling well into snow leopard heights. He assumed it was climate change. "The species are on the move," he said.

Others are also convinced familiar landscapes are changing before their eyes, and that the cause is global warming. Not far from Everest, tucked into the mountains at about 5,050m, near the village of Lobuche, there's a three-storey glass pyramid that looks like it belongs on the set of an Austin Powers movie.

It's a high-altitude research station run by an Italian organisation dedicated to research on the Himalayas. Earlier this year, crews from the pyramid, as it is usually known, strapped on crampons and installed a weather station on the south col of Everest at about 8,000m. There are plans to go even higher next spring, placing a weather station on the summit itself.

The data from the south col, on temperature, air quality and ozone levels, has just started coming in. Ka Bista, a Nepali staffer who mans the pyramid when the Italians are back in Europe, says the changes are evident right now. "Since the last five or 10 years before and now, there are many differences in the glaciers. Before you could see ice," Bista said, pointing to the bare black rock visible through the pyramid. "Yearly the snow is melting and going further up the mountain, and the temperature is also going up." Winters have also grown milder, he said. In 2006, typical February temperatures were minus 23 or 24 celsius. This past February it was almost balmy in comparison, Bista said, at minus 17 or 18 degrees.

The changes are disorienting for local people, Bista said. "Ten years ago a trekking guide could tell you the name of every mountain, but now they are all completely black and the guides can't recognise their names."

What became clear on the Mountain Institute expedition, however, was the disconnection between such personal experiences and the scientific process. People living in the mountains say they can see signs of climate change. Climbers who have scaled Everest say they can see evidence of climate change.

The problem is that it is immeasurably harder to produce conclusive scientific documentation of those changes – which glaciers are melting and how fast? — and Himalayagate has made scientists especially cautious.

Put simply, the region is just too big, and too remote. Between them the mountains of the Himalayas, the Hindu Kush, Karakorams, Pamirs and Tien Shan store more ice than anywhere outside the north and south poles. There are believed to be about 15,000 glaciers across the Himalayas – 3,800 or so in Nepal alone, according to the International Centre for Integrated Mountain Development, in Kathmandu.

But even that number should not be taken as gospel, according to Dorothea Stumm, of Icimod. Scientists can't even agree on which mountain ranges should be included in the count. "Currently it is safer to talk about several tens of thousands of glaciers instead of a specific number," Stumm wrote in an email.

Then, there is the question of size. "How big does an ice patch need to be to be called a glacier?" said Stumm. Smaller ones might not even show up on low-resolution satellite images. And how do you count a bigger glacier that has split into two smaller blocks of ice? And it's not as if scientists can just pop out for an afternoon and measure some of the large glaciers in the Himalayas. The Khumbu glacier, which runs alongside Everest, is a good eight or nine days' walk from the nearest airport at Lukla. The glaciers of Bhutan are even further removed, and the Siachen glacier is an actual battlefield, with India and Pakistan maintaining troops there at 6,000m.

"Himalayan glaciers are much more remote," said Andreas Kaab of the University of Oslo, who was not on the expedition. "From Zurich you take the train a few hours, you take a cable car and there you are at the glacier and you take your measurements," he said.

The result, according to Byers, is a big knowledge gap. Scientists have access to satellite images of the Himalayas, but compared with other regions, such as the Andes or the Alps, there is relatively little on-the-ground research. Satellite imagery only gives a partial picture; it can reveal a glacier shrinking in length, but it gives little indication of whether the ice is thinning. In addition, record-keeping on glaciers and temperatures got under way relatively late in Nepal.

"It's pretty much a vacuum, the Himalayas," Byers said. "The Alps and Andes are well studied. I think they have a good database on glaciers there. The Himalayas, in terms of these sorts of studies – there are fewer than elsewhere In the Himalayas for reasons of logistics, hardship and altitude there still hasn't been a whole lot of detailed field work done, on-the-ground field work."

Nevertheless, some definitive patterns are emerging. In Nepal, south-facing glaciers, especially at lower elevations below about 5,000m, are thinning and growing shorter at a rapid rate. Some – especially the glaciers that are relatively clear of debris — have already disappeared.

Those glaciers covered in a sufficiently thick mask of grit and rock have a better chance. If the covering is thick enough, say greater than a metre, the layer of rocks and debris acts like an insulation blanket, preserving the glacier from more rapid warming. A thin coating seems to have the opposite effect, however, absorbing the sun's rays, and speeding the melting process.

But even the greatest glaciers, such as Khumbu, are in retreat. On the way up to base camp, the signs seem evident in the small ponds now forming on the surface. "There are a lot of things on the surface of the Khumbu glacier. It is a sign of degradation," said Petrov. "Of course, this glacier is not degrading so intensely as smaller glaciers, but if you compare the old glacier 40 or 50 years ago with the glaciers of today, then it is retreating."

So where does that leave the Himalayan glaciers? Will there still be glaciers in the big ice repository a generation from now? Probably, but don't count on it for much longer than that, Byers said. "Your grandkids are going to go up there and see glaciers. I just don't believe in this scenario of all that ice being gone in the next 30 years or so."

But he added: "If you are looking really long-term, say 100 or 200 years from now, at current warming trends I would say that the outlook is not good, not good at all."

• This article was amended on 27 September 2011 to replace the term "climate-change" deniers with "climate-change sceptics" in accordance with the [Guardian and Observer Style Guide](), which states: "Rather than opening itself to the charge of denigrating people for their beliefs, a fair newspaper should always try to address what it is that people are sceptical about or deny. The term sceptics covers those who argue that climate change is exaggerated, or not caused by human activity."

theguardian

Oct. 10, 2011, The Guardian, Suzanne Goldenberg

Glacier Lakes: Growing danger zones in the Himalayas

Fears rise of huge outburst flooding in the Himalayas as glaciers melt due to climate change

Link to video.

It's strangely calming to watch the Imja glacier lake grow, as chunks of ice part from black cliffs and fall into the grey-green lake below.

But the lake is a high-altitude disaster in the making – one of dozens of new danger zones emerging across the Himalayas because of glacier melt caused by climate change.

If the lake, situated at 5,100m in Nepal's Everest region, breaks through its walls of glacial debris, known as moraine, it could release a deluge of water, mud and rock up to 60 miles away. This would swamp homes and fields with a layer of rubble up to 15m thick, leading to the loss of the land for a generation. But the question is when, rather than if.

Mountain regions from the Andes to the Himalayas are warming faster than the global average under climate change. Ice turns to water; glaciers are slowly reduced to lakes.

When Sir Edmund Hillary made his successful expedition to the top of Everest in 1953, Imja did not exist. But it is now the fastest-growing of some 1,600 glacier lakes in Nepal, stretching down from the glacier for 1.5 miles and spawning three small ponds.

At its centre, the lake is about 600m wide, and according to government studies, up to 96.5m deep in some places. It is growing by 47m a year, nearly three times as fast as other glacier lake in Nepal.

"The expansion of Imja lake is not a casual one," said Pravin Raj Maskey, a hydrologist with Nepal's ministry of irrigation.

The extent of recent changes to Imja has taken glacier experts by surprise, including Teiji Watanabe, a geographer at Hokkaido University in Japan, who has carried out field research at the lake since the 1990s.

Watanabe returned to Imja in September, making the nine-day trek with 30 other scientists and engineers on a US-funded expedition led by the Mountain Institute. He said he did not expect such rapid changes to the moraine which is holding back the lake.

"We need action, and hopefully within five years," Watanabe said. "I feel our time is shorter than what I thought before. Ten years might be too late."

Unlike ordinary flash floods, a glacier lake outburst is a continuing catastrophe.

"It's not just the one-time devastating effect," said Sharad Joshi, a glaciologist at Kathmandu's Tribhuvan University, who has worked on Imja. "Each year for the coming years it triggers landslides and reminds villagers that there could be a devastating impact that year, or every year. Some of the Tibetan lakes that have had outburst floods have flooded more than three times."

But mobilising engineering equipment and expertise to a lake 5,100m up and several days' hard walking away from the nearest transport hub is challenging in Nepal, one of the poorest countries in the world. People living in the small village of Dingboche below the lake say scientists and government officials have been talking about the dangers of Imja for years.

Some years ago one of the visiting experts was so convincing about the dangers of an imminent flood that the villagers packed up all their animals and valuables and moved to the next valley. They came back after a week when the disaster did not materialise, but say it's hard to dismiss the idea that there could be a flood one day.

"When I was 21 I went to the lake and it was black and really small," said Angnima Sherpa, who heads a local conservation group in Dingboche. "Two years ago I went there and it was really big. I couldn't believe it could get so big. It was really scary."

But scientists and engineers still cannot agree on whether to rate Imja as the most dangerous glacier lake in the Himalayas, or a more distant threat.

Mobilising international assistance for large-scale engineering projects during a global recession is also difficult. The Mountain Institute's initiative was to call in experts from the Andes, where Peruvians have developed systems for containing glacier floods since a disaster in the 1940s killed nearly 10,000 people.

Cesar Portocarrero, who heads the department of glaciology at Peru's national water agency, has overseen engineering works to drain more than 30 glacier lakes, building tunnels or channels to drain the water and reduce the risk of flooding.

But he conceded it would be an enormous challenge to apply these methods at Imja.

"It's not easy to say 'we are going to siphon the water out of the lake'," Portocarrero said. "Where do you find the people who can work at high altitudes? How do you move in the equipment? What do you do in bad weather? You have to have exhaustive planning." There are also other contenders for immediate action, with some 20,000 glacier lakes across the Himalayas, although many are concentrated in the Everest region. Bhutan alone has nearly 2,700.

Three of those, known as the Lunana complex, are practically touching, increasing the possibility of cascading floods far more devastating than any rupture at Imja.

"If the barrier fails between them we are going to have a massive glacier lake outburst flood," said Sonam Lhamo, a geologist for the Bhutanese government.

The United Nations Development Programme and other agencies have supported a project to drain the lakes but those funds are running out.

John Reynolds, a British engineer and expert on glacier lakes who has worked in Nepal, argues that the international community has focused on Imja because of its proximity to Everest and trekking routes popular with western tourists. He says there are other, more hazardous lakes elsewhere.

The Nepali government ranks Imja among the six most dangerous glacier lakes in the country largely because it is growing so quickly. More than 12 other such lakes are also seen as high risk.

But Reynolds argued: "Just because a lake is getting bigger doesn't necessarily mean that it is getting more hazardous. As the climate is changing, generally speaking more glacial lake systems are forming.

"The question is how to decide which ones are hazardous now and which ones have the propensity to become hazardous in the future."

Imja, though fast-growing, is held in by a relatively wide moraine, which makes it secure in comparison to some others.

Most glacial lake floods begin as high-altitude tsunamis. A large block of ice falling from a glacier at great height sets off a series of giant waves that wash over the moraine.

That's not such a risk for Imja. The glaciers feeding the lake are gradual in slope, which reduces the risk of a large chunk of ice falling from a great height and setting off large waves.

Watanabe concedes the geography of the lake could keep disaster at bay, at least in the next year or two. But, he says, there are signs that an outlet channel at the bottom of the lake may be widening dangerously.

Reynolds said Nepal and the international community need to think of a Himalaya-wide action plan.

"As the climate is changing more glacial lake systems are forming," he said. "The question is how to decide which are hazardous now and which are going to become hazardous in the future."

theguardian

Oct, 12, 2011, The Guardian, Suzanne Goldenberg

Calls for long-term Everest waste management plan – starting with toilets

Nepalese government urged to install portable toilets at Everest base camp, and devise strategy to keep region clean

The Saving Mount Everest Clean-Up Expedition team bring over 8 tonnes of rubbish from Mount Everest and its trekking trails Photograph: savingmounteverest.org

A Nepali environmental group is petitioning the government in Kathmandu to put portable toilets on the top of the world – Everest base camp – as part of a new management plan for the high-altitude region.

The environmental group, Eco Himal, argues public toilets would make it easier to maintain a clean environment at base camp, which sees dozens of climbing expeditions a year.

It is also proposing public toilets at other popular peaks in the Everest region such as Pumori, Ama Dablam, and Island Peak, said Eco Himal's director, Phinjo Sherpa.

Everest base camp, a rocky plateau at 5,300m that is the starting point for climbing expeditions, has for years been the focus of clean-up operations after a series of stinging reports in the 1990s about rubbish and filth in what had once been pristine environments.

This year, Eco Himal led a push to recover 8,000kg of rubbish from base camp as well as Camp 1 and 2 – including the wreckage from an Italian helicopter crash.

But Sherpa argued that such sporadic clean-up efforts – though well-meaning – do not go far enough.

His organisation is pressing the government to develop a broader management plan that would set aside adequate funds to conserve the Everest region.

"Everybody talks about waste in the mountains but nobody talks about proper solutions," Sherpa said. "Cleaning up Everest every once in a while does not help. The main thing is management, waste management

Link to video.

Expeditions have already made great strides to reduce their impact on Everest, carting away rubbish and swapping solar panels for conventional generators.

But Sherpa argued that portable toilets would make it easier for the organisations overseeing clean-up at base camp to deal with the problem of human waste.

"During the season time, there are thousands of climbers and most of the expeditions have toilet tents with barrels up there. But porters and others who need them normally just go back and forth," he said.

"Having one or two toilets in the base camp could solve this problem."

However, the proposal has critics even within the coalition trying to develop the sustainable management plan for Everest.

Wangchhu Sherpa, president of the Everest Summiteers Association, which is also trying to press the Nepal government to do more for the region, said his group did not support the proposal.

theguardian

Oct. 24, 2011, The Guardian, Suzanne Goldenberg

The mission to clean up Mount Everest

Environmentalists in Nepal are pressing the government to keep the Himalayas free from litter

Mount Everest – more than 2,500 people have reached the summit since Edmund Hillary in 1953. Photograph: Desmond Boylan/REUTERS

The people who set out to climb Everest spend months dreaming about reaching the summit. They pay $65,000 (£41,000) in fees to the Nepali government; they train, trek for days, endure extreme discomfort, even danger. So it should be a simple thing to get them to pick up after themselves.

Apparently not. Nearly 60 years after Edmund Hillary conquered Everest, and 30 years after climbing turned commercial, the region is still struggling to deal with mass tourism.

By the standards of the 70s, when the main climbing routes were littered with discarded tents and food packets, Everest is a lot cleaner, with just a smattering of plastic bottles and sweet wrappers on the rocky plateau that is base camp. But a Nepali environmental coalition is pressing the government in Kathmandu to adopt a new management plan to safeguard the Himalayas in the age of mass tourism – and to make amends for the environmental sins of the past.

"Everybody talks about waste in the mountains but nobody talks about proper solutions," says Phinjo Sherpa, director of Eco Himal. "Cleaning up Everest every once in a while does not help. The main thing is management, waste management." The group has lodged a plan with the government that calls for tougher penalties against litterbugs at Everest and the surrounding areas. They are also pushing for the installation of portable toilets at base camp and investment in waste treatment facilities – which currently do not exist in the region – with proposals for five incinerators and sewage treatment plants.

It's difficult to tread lightly in the high-altitude environment, especially in areas this remote. The first expeditions to Everest were monumental in scale. The 1953 attempt, which brought success to Hillary, set off from Kathmandu with 1,200 porters for their equipment, according to Kancha Sherpa, the last surviving member of the team that made it to base camp.

The 1953 expedition required 25 wooden crates just to carry the coins they would spend along the way. A single oxygen bottle weighed 15kg. As for dealing with the detritus of such a huge human endeavour, Kancha looks blank. "You have to remember that was a long time ago. Things were very different then," he says. Even Hillary admitted to leaving equipment behind, and more than 2,500 people have made it to the summit since his day. The heavy traffic left its mark. "People were careless. They would take a rubbish bag but they would still leave stuff behind," said Tshering Tenzing Sherpa, an official of the Sagarmatha Pollution Control Committee, the NGO charged with overseeing the Everest cleanup.

Modern expeditions are much more conscious of their footprint. Groups must pay a $4,000 (£2,500) deposit on their equipment – in the hope that they will carry down everything they brought. Repeat visitors to Everest see a difference. "It's visibly and spectacularly better," says Jan Morava, an electrical engineer from the Toronto area who was attempting the summit with his brother and a climber from the UAE. "There were piles of rubbish in base camp before."

But conservation groups say the deposit is small compared with the other expenses associated with an ascent on Everest. They also argue the Sagarmatha Pollution Control Committee lacks the resources to keep up with all the groups climbing Everest and to make sure that do indeed carry all their equipment back down to Kathmandu.

The committee says it brought back 25 tonnes of rubbish from Everest last spring – including 12,000kg of paper and plastic and 11,250kg of human waste. But conservationists argue that waste disposal is haphazard. There are rubbish dumps with heaps of tuna cans and plastic bottles only a few minutes' walk away from villages on the trekking trail.

On a trek near the village of Lobuche last May, Alton Byers of the Mountain Institute came across a 10 sq metre open pit of human waste, hauled down from Everest, close to a seasonal stream. The pit had been covered over by the time of a subsequent visit in May.

And, says Tshering, there is plenty more detritus of the past still out there – rubbish discarded by climbers years and even decades ago, preserved in ice and snow. "Just above the ice falls at crampon point you can see cans from 10, 20, 30 years ago or even older," Tshering says. "There's a lot of old rubbish out there."

Other high peaks less famous than Everest are even dirtier, notes Tshering. And with climate change, snow and ice on mountaintops is melting, exposing even more rubbish. "We are in a garbage race," he says.

![NATIONAL GEOGRAPHIC Daily News]

Sept. 14, 2011, National Geographic, Andrew Howley

Expedition to a New Glacial Lake

Link to Video/Story.

The following is edited from several recent posts from the Imja Lake Expedition team at The Mountain Institute. Follow the full series at http://www.mountain.org/blog/.

Glaciers Are Melting, and We're Taking Action!

The mountain world is changing faster than any of us could have imagined: these changes threaten all of us who live downstream. Glaciers are melting, rainfall patterns are changing, and the world's most important fresh water supplies are endangered.

The Mountain Institute is currently leading a month-long series of workshops and an expedition to Imja Lake, a newly-formed, potentially dangerous, glacial lake near Mount Everest.They 're going to the field and talking to local people in order to research and educate.

The team is made up of over 30 engineers, photographers, journalists, and world-class scientists from Tajikistan, Uzbekistan, Kyrgyzstan, Pakistan, Nepal, China, Bhutan, Peru, Bolivia, Japan, the US and Europe to the field to exchange knowledge with local people about monitoring and controlling glacial lakes. We'll evaluate the danger of Imja, and determine how to control it so it can supply fresh water safely and reliably to downstream communities for drinking, irrigation, and the generation of electricity.


Ang Rita Sherpa (Photo by Brendan Hickey/The Mountain Institute)

The Local Point of View

Ang Rita is a long-time conservationist and activist for the Sherpa people and culture; he has been The Mountain Institute's Senior Program Manager in Nepal for years. As a native to the region, he has a unique view into what makes this expedition stand out:

"In the past, scientists met with Sherpa villagers interested in the future of the Imja valley. But the scientists only discussed the threats, not the solutions. My people were unhappy. So, The Mountain Institute promised an expedition with solutions. And now, every morning, people call me to ask when the expedition will reach their village – they are very excited for us to talk to them about solutions to the threats from glacial lakes, and how the water from the lakes can be used to help local communities with irrigation, electricity and other practical purposes."

International Inspiration and Collaboration

One might think that the Peruvian scientists, familiar with the high Andes, would feel right at home in the Himalaya. There is however one major distinction that is noted repeatedly: "Peru is very different from the Himalayas because here the scale is just huge."


Jorge Recharte (Photo by Daniel Byers/TMI)

In Peru, roads make most of the dangerous lakes accessible within one or two days; but Imja lake is at least a week's trek from Lukla, the nearest large village.

Jorge Recharte, the director of the Andean Programs at TMI commented on the benefits of having such a diversity of backgrounds and perspectives on the expedition:

"There was a conversation last night between Ang Rita, a Nepali, and Cesar, a Peruvian, discussing what's possible… and what's not possible – it is just fantastic, the sparks of ideas that happen when you bring [together] different backgrounds, different nationalities. [...] There is a common goal to understand glacial lakes, to share our respective experiences… the process of working through that, and then collaborating. If we continue as we have so far these two days, the result will be very powerful."


Technology at the Top of the World. (Photo courtesy The Mountain Institute.)

The Technical Challenges

Since the team is in such a remote location, all communications are going out via a satellite phone. Physically it looks like an indestructible cellphone with an 80′s-style antenna. It's not very fast, but up here it's the only option.

To facilitate writing posts, they've hauled a pair of netbooks up with plenty of spare batteries. With any luck the power will hold out through the remotest stretch of the expedition.

LATEST UPDATE: Arrival at Imja Lake!

9/12/11 — This morning we woke to a dusting of fresh powder, inspiring thoughts of the song "Snow, snow, snow" from the movie-musical *White Christmas*. With Bing Cosby's melodies in head the team gathered for breakfast, only to find our departure to Imja Lake was delayed…


Imja Base Camp (photo by Daniel Byers/TMI)

Luckily, the slushy rain let up around 10am and our expedition was able to depart after lunch. A few hours later, we found ourselves in a neon yellow tent village at Imja Lake Base Camp. We have arrived! For the next three days, we will explore the lake, exchange with locals, and brainstorm future research and action items. And with walls of mountains surrounding us and the lake in our backyard, inspiration will surely flow.

Follow the full blog series of the Imja Lake Expedition at http://www.mountain.org/blog/.

Sept. 30, 2011, National Geographic, Andrew Howley

Your Questions Answered From the Mountain Top

Recently, National Geographic Facebook fans posted their questions for members of The Mountain Institute's international expedition to a potentially dangerous new glacial lake in the Himalayas.

The team responded via satellite phone with audio answers and photos. Listen below, or scroll to the bottom to read the transcripts.

AUDIO TRANSCRIPTS

Question from Moira Brigitte Rauch: Is there any correlation with the data they are collecting and other parts of the World?


Jorge Recharte (Photo by Daniel Byers/TMI)

Answer from Jorge Recharte: Thank you for your question Moira. I'm Jorge Recharte from Peru. I work with the Mountain Institute in Cordillera Blanca, which is a very large glacier region in central Peru. And yes, the issues that we have seen here at Imja Lake in the Himalayas are very similar to what is being observed in the Andes of Peru.

Glaciers are receding very fast and behaving in similar ways. Now glacier lakes are forming in very much the same fashion—both in Peru and in the Himalayas. The challenges that people are facing are also very much the same in terms of understanding the challenges they're facing and how to get organized to respond to these problems.


Researchers from the Himalayas and the Andes share their thoughts at the top of the world. (Photo by Daniel Byers/TMI)

In fact, one of the purposes of the expedition is to find out how we can learn from one region to the other because these issues are so similar. We're trying to share learning both in terms of biophysical aspects of glaciers receding and lakes forming and also in terms of social organization to respond to these challenges.

Question from Jennifer Lynn: What is your greatest hope or fear in this adventure?


Alton Byers (Photo by Daniel Byers/TMI)

Answer from Alton Byers: Hi Jennifer, this is Alton Byers speaking. I'm the Director of Science and Education at the Mountain Institute and also leader of this expedition.

My greatest hope for this expedition is that it leads to even greater collaboration and research between scientists from different countries from all over the world—countries that are experiencing the new hazard of glacial lakes and glacial lake outburst floods.

My greatest fear is that of the weather, and also altitude. At any time, this whole expedition could be scrapped if it rains too much and the planes can't fly or we can't walk —and number two—if somebody gets sick with altitude.

Fortunately, this expedition has been absolutely blessed. We've had nothing but good weather the whole time, and because we know how to deal with altitude, if somebody comes down with the symptoms we send them down to a lower altitude where they recover for a day or two and the rejoin us. Thanks very much for your question.


With good weather on their side, the team cruises along a narrow mountainside path. (Photo by Daniel Byers/TMI)

Question from Noor Al-Iman: Are the lakes of any benefit? (fishing, tourist attraction, etc)

Answer from Dale McKiney: My name is Daene McKinney. I'm a civil engineer working on glacial lake problems. Thank you for your question, Noor.

These lakes don't have much benefit in terms of fisheries because of the high sediment content of the water. Tourism is mostly of interest because of the mountains in these areas, but the lakes do offer some benefit. The most benefit probably comes from potential hydro-power generation and also downstream uses for irrigation—or perhaps domestic municipal water supply.

The full team stands proudly beneath the soaring peaks of the Himalayas. (Photo by Daniel Byers/TMI)

Link to Story with Audio.

Oct. 24, 2011, ClimateWire, Lisa Friedman

In the land where 'the mountains used to be white,' science works slowly

Namdu Sherpa picked potatoes as a girl in Namche Bazaar, the only economy in her village before Mount Everest-bound adventurers made a habit of trekking through with their Gore-Tex jackets and titanium walking poles. Almost overnight, the 75-year-old great-grandmother said, her small trading post in Nepal's Khumbu Valley transformed into a bustling tourist hub of lodges and cyber cafes.

Nodding toward her gleaming Samsung refrigerator and microwave, Namdu Sherpa said life has changed dramatically from the days of tending crops and cooking over firewood. Through the years, though, one thing remained constant: the majestic snow-capped Himalayan mountains. Until recently, that is.

Namdu Sherpa, 75, says villagers in her town of Namche Bazaar see changes on the mountain, but don't understand them. Photo by Lisa Friedman.

"The mountains used to be white. Now, the mountains don't seem so white. It's all rocks," she said, looking out her kitchen window at the cloud-covered peaks. "We don't know exactly what's happening."

Neither, it seems, do scientists. There is widespread acknowledgement that the snow cover in the Himalayan mountain range is declining, and that many glaciers are retreating at a rapid rate. But everything else -- from where melt is occurring to how fast, how much melt contributes to downstream water use, and even to what extent greenhouse gas emissions play a role compared to soot -- is being answered at a glacial pace.

The difficulty in obtaining solid data on the mountain range is rooted in both the area's remoteness and regional political rancor. Compounding the uncertainty is doubt about the credibility of the Intergovernmental Panel on Climate Change, which had stated in 2007, wrongly, that Himalayan glaciers could melt by 2035. Scientists say the doomsday scenario error did lasting damage to popular understanding of the Himalayas. It also underscored how tenuous their grasp on the region really is.

"The knowledge gap is large," said Richard Armstrong, a glaciologist and senior research scientist at the National Snow and Ice Data Center in Boulder, Colo. Armstrong and dozens of other scientists met in Washington, D.C., this month with the National Academy of Sciences to begin to tease out the answers to some of the most vexing questions.

Scientists note that the Himalayan glaciers are sensitive to summer warming because both accumulation and ablation, or melting, primarily occur during the summer monsoon season. That means small increases in summer temperatures accelerate the melt while at the same time causing precipitation to fall as rain, which flows away, rather than snow.

Romance, exaggeration overlie a multitude of risks

"Glaciers are a dynamic system, sort of a conveyor belt of ice from a higher elevation to a lower elevation," each part with its own individual behavior, he said. If everything is going well for a glacier, the mass it loses by seasonal melts at lower elevations is replaced by snowfall at higher elevations -- which then is packed down into ice and and carries its mass downhill over decades.

Nepal's Khumbu Glacier, one of the most visited in the Himalayas, is retreating at an average speed of 20 meters per year. But scientists say it's impossible to generalize about glacier melt in the Himalayas, where some are retreating faster than others and some are even growing. Photo courtesy of Flickr.

Particularly in the eastern Himalayas, glaciers in lower elevations "are definitely seeing a warming," Armstrong said, while those above 18,000 feet appear far more resilient. Meanwhile, contrasting patterns of growth are evident in the western Himalayas among some 230 glaciers.

Armstrong rattled off a handful of hyperbolic statements that have made their way into the mass media -- like that glaciers are melting faster in the Himalayas than anywhere else in the world, or that glacier melt will lead to catastrophic floods throughout Asia. There is little or no scientific evidence for some of these claims, he argues.

While Armstrong chalks up exaggerations to the mysterious romanticisms that people apply to glaciers, he worries that those claims ultimately do a disservice to grasping the damage that the retreat of lower-elevation glaciers in the eastern Himalayan region will have on the wider region's water resources.

"If a glacier can melt fast enough to cause a flood in Bangladesh, we're in bigger trouble than we thought," he said. Like other outsized claims, he said, "it's an example where there's not a lot of good data available, so if there's some emotional trigger ... people can say whatever hits them emotionally, and you can't prove them wrong."

But understanding the area of what is called the Hindu Kush-Himalayan region is crucial. The remote mountain region encompasses about 15,000 glaciers -- sometimes referred to as the planet's third pole because it is the largest concentration outside of the Arctic and Antarctic -- and sweeps through Pakistan, India, China, Nepal and Bhutan. The melted snow becomes the mother of headwaters for Asia's seven largest rivers, which in turn sustain some 1.5 billion people.

While new research is showing that not all glacier-fed rivers are as dependent on melt as others, the Indus River is heavily fed by the Himalayan snow and ice melt (*see related story*). In Pakistan, the Indus and its tributaries keep more than 80 percent of the country's agricultural land fertile. One U.S. Agency for International Development (USAID) report predicts Pakistan could face a "terrifying" 30 to 40 percent drop in Indus River Basin flows over the coming century.

Glimmers of grief for huge populations

Some scientists predict the Ganges River could drop off by two-thirds, affecting the more than 400 million people who depend on it. The Brahmaputra River flows through China and India into the Bay of Bengal in Bangladesh. If that river dries up, so will water availability for the millions of people along the Brahmaputra in Assam and Bangladesh.

In the short term, the melting glaciers mean increased risk of mudslides, erosion and flooding. Countries like Bhutan and Nepal are particularly at risk of glacier lake outburst floods, or GLOFs, that threaten to destroy entire villages.

"All over the world, the cryosphere is being affected, but in this region especially you see the huge populations that are being sustained by agriculture," said Syed Iqbal Hasnain, a distinguished visiting fellow at the Stimson Center and chairman of the Glacier and Climate Change Commission established by the state government of Sikkim in India.

"The global community has to come forward and do something," he said. "It's critical, because of the huge populations in this entire region which are directly dependent on this water."

The physical act of studying Himalayan glacier melt is no easy task. Basic field measurements present a formidable challenge, since even the most rugged of researchers, able to hike for weeks through pine forests and Sherpa villages at high altitudes, can access only lower-elevation glaciers.

Recently, a group of scientists led by the Mountain Institute and funded by USAID trekked for 18 days through Nepal's Khumbu Valley merely to observe the severely threatened Imja Lake. Just arriving at the growing glacier lake took eight days of uphill hiking, with time built in to adjust to the 5,000-meter climb.

Dirk Hoffmann, a geographer with the Bolivian Mountain Institute who was on the trek, said getting to Imja -- still one of Nepal's most accessible and most studied glacier lakes -- put the difficulties of research in Bolivia's Apolobamba Mountain Range into perspective.

"The Apolobamba is little-explored, and the least accessible mountain range in the Andes. But that is relative, as I learned here in the Himalayas," Hoffmann said.

And the dangers have not been limited to exhaustion and altitude sickness.

How wars and politics work against research

Nepal, while currently peaceful, is recovering from a decadelong civil war. Teiji Watanabe, a professor of environmental science at Hokkaido University in Japan who has studied Imja Lake for more than three decades, recalled how the perils of research became almost too great in the 1990s. Working in a lodge caught between the Nepalese police forces headquarters and Maoist insurgents, Watanabe said he still remembers shouting "Japanese! Scientist!" every time he raced to the outhouse.

Meanwhile, the Siachen Glacier in Kashmir -- sometimes called the highest battleground on Earth at 20,000 feet -- feeds Pakistan's Indus River, but is "impossible to study," said Saleem Ali, a professor of environmental studies at the University of Vermont. India and Pakistan maintain a large military presence in the region, and only a select group of Indian scientists has ever been able to conduct field research on the glacier.

Perhaps not surprisingly, cooperation in a region so rife with conflict is far from easy. Daan Boom, a knowledge management specialist with the International Centre for Integrated Mountain Development (ICIMOD) in Kathmandu, calls the lack of regional cooperation one of the greatest challenges in addressing the impacts of hydrological changes in the Himalayas.

"There's not enough data to predict what's going on in the mountains, and obtaining data is difficult," he said. "Regional cooperation is not optimal for data sharing."

That's slowly starting to change, and activists are eyeing a major ministerial-level conference next month in Bhutan as a place where the region could finally start to make strides in working together to promote Himalayan health. The Climate Summit for a Living Himalayas, as it is being called, is for the first time bringing together regional governments to try to develop a 10-year blueprint for climate change adaptation in the region. Madhav Karki, deputy director-general of ICIMOD, called the Bhutan summit "a truly unique approach," and said he hoped such a road map could be replicated elsewhere.

Yet even here the divisions are visible. Bhutan, Nepal, India and Bangladesh are co-hosting the event, and so far, there is little evidence of Pakistan or China's involvement. Organizers officially say the omission is simply geographic -- the eastern Himalayas require urgent action -- but activists quietly acknowledge that regional politics play a part, as well.

In the meantime, all people in countries like Nepal can do is watch as the stunning scenery outside their homes is perhaps forever altered.

"We used to have snow -- lots of snow. Now we see less snow, and even when it does snow, because the land is warmer, it melts. The glaciers are also melting. That we know," said Ang Phurba Sherpa, 69, the former head of Namche Bazaar's governing board. But, he said, despite the several workshops on global warming that local activists have sponsored, local people are not sure what they can do to stop the changes they see around them.

"We know that change is in the mountain," Ang Phurba Sherpa said. "The glacier is so much changed. We have town meetings about global warming, but the only thing they can do is advise the people and make them aware."

THE THIRD POLE — AN E&E SPECIAL REPORT

Oct. 24, 2011, ClimateWire, Lisa Friedman

New research sheds doubt on doomsday water shortage predictions

From the Andes to the Himalayas, scientists are starting to question exactly how much glaciers contribute to river water used downstream for drinking and irrigation. The answers could turn the conventional wisdom about glacier melt on its head.

A growing number of studies based on satellite data and stream chemistry analyses have found that far less surface water comes from glacier melt than previously assumed. In Peru's Rio Santa, which drains the Cordilleras Blanca mountain range, glacier contribution appears to be between 10 and 20 percent. In the eastern Himalayas, it is less than 5 percent.

"If anything, that's probably fairly large," said Richard Armstrong, a senior research scientist at the Boulder, Colo.-based Cooperative Institute for Research in Environmental Sciences (CIRES), who studies melt impact in the Himalayas.

"Most of the people downstream, they get the water from the monsoon," Armstrong said. "It doesn't take away from the importance [of glacier melt], but we need to get the science right for future planning and water resource assessments."

Glacier-fed rivers like the Ganges support more than 1.3 billion people in Asia. But new research questions just how much influence the melting glaciers will have on water availability for people downstream. Photo courtesy of Flickr.

The Himalayan glaciers feed into Asia's biggest rivers: the Indus, the Ganges and the Brahmaputra in India, Pakistan and Bangladesh, and the Yellow and Yangtze rivers in China. Early studies pegged the amount of meltwater in these river basins as high as 60 or 70 percent. But reliable data on how much water the glaciers release or where that water goes have been difficult to develop. Satellite images can't provide such regular hydrometeorological observations, and expeditions take significant time, money and physical exertion.

New methods, though, are refining the ability to study this and other remote glacial mountain ranges. Increasingly, scientists are finding that the numbers vary depending on the river, and even in different parts of the same river.

Creeping hyperbole

"There has been a lot of misinformation and confusion about it," said Peter Gleick, co-director of the California-based Pacific Institute for Studies in Development, Environment and Security. "About 1.3 billion people live in the watersheds that get some glacier runoff, but not all of those people depend only on the water from those watersheds, and not all the water in those watersheds comes from glaciers. Most of it comes from rainwater," he said.

A key step forward came last year when scientists at Utrecht University in the Netherlands, using remote sensing equipment, found that snow and glacier melt is extremely important to the Indus and Brahmaputra basins, but less critical to others. In the Indus, they found, the meltwater contribution is 151 percent compared to the total runoff generated at low elevations. It makes up about 27 percent of the Brahmaputra -- but only between 8 and 10 percent for the Ganges, Yangtze and Yellow rivers. Rainfall makes up the rest.

That in itself is significant, and could reduce food security for 4.5 percent of the population in an already-struggling region. Yet, scientists complain, data are often inaccurately incorporated in dire predictions of Himalayan glacial melt impacts.

"Hyperbole has a way of creeping in here," said Bryan Mark, an assistant professor of geography at Ohio State University and a researcher at the Byrd Polar Research Center.

Mark, who focuses on the Andes region, developed a method of determining how much of a community's water supply is glacier-fed by analyzing the hydrogen and oxygen isotopes in water samples. He recently took that experience to Nepal, where he collected water samples from the Himalayan glacier-fed Kosi River as part of an expedition led by the Mountain Institute.

Based on his experience in the Rio Santa -- where it was once assumed that 80 percent of water in the basin came from glacier melt -- Mark said he expects to find that the impact of monsoon water is greatly underestimated in the Himalayas.

Jeff La Frenierre, a graduate student at Ohio State University, is studying Ecuador's Chimborazo glacier, which forms the headwaters of three different watershed systems, serving as a water source for thousands of people. About 35 percent of the glacier coverage has disappeared since the 1970s.

La Frenierre first came to Ecuador as part of Engineers Without Borders to help build a water system, and soon started to ask what changes in the mountain's glacier coverage would mean for the irrigation and drinking needs of the 200,000 people living downstream. Working with Mark and analyzing water streams, he said, is upending many of his assumptions.

Doomsday descriptions don't fit

"The easy hypothesis is that it's going to be a disaster here. I don't know if that's the case," La Frenierre said. He agreed that overstatements about the impacts are rampant in the Himalayas as well, saying, "The idea that 1.4 billion people are going to be without water when the glaciers melt is just not the case. It's a local problem; it's a local question. There are places that are going to be more impacted than other places."

Those aren't messages that environmental activists will likely find easy to hear. Armstrong recalled giving a presentation in Kathmandu on his early findings to a less-than-appreciative audience.

"I didn't agree with the doomsday predictions, and I didn't have anything that was anywhere near spectacular," Armstrong said. But, he added, "At the same time, it's just basic Earth science, and we want to do a better job than we have been."

The more modest numbers, they and other scientists stressed, don't mean that glacier melt is unimportant to river basins. Rather, they said, they mean that the understanding of water systems throughout the Himalayan region must improve and water management decisions will need to be made at very local levels.

"We need to know at least where the water comes from," Armstrong said. "How can we project into the future if we don't know where the water comes from now?"

Oct. 25,2011, ClimateWire, Lisa Friedman

Can Asia put aside its rivalries to deal with the Himalayan melt?

In the weeks before a major meeting of Indian and Pakistani ministers, disaster experts and youth leaders in Lahore to discuss Himalayan glacier melt, Malini Mehra avoided reporters.

The normally outspoken director of an Indian environmental organization that was helping to organize the conference, Mehra said she had seen too many exchanges between India and Pakistan on critical water issues disintegrate in a pool of visa denials and political acrimony. Too much attention, she worried, could doom her conference to the same fate.

Countries affected by Himalayan glacier melt share river headwaters, but not data. Experts say climate change is making secrecy over water flow data untenable. Click the map for a larger version. Photo courtesy of Sandia National Laboratories.

"Before I started this, I was warned that it was impossible," Mehra said. "At the beginning, we were beset with fear and suspicion that it was going to be derailed by people who would prefer that Indians and Pakistanis didn't have a full, frank and healthy dialogue on water impacts and how to manage disasters effectively. I heard story after story of just absolute horror."

The conference went off without a hitch, but even those who hosted the exchange say it was just a drop in the bucket of badly needed scientific and policy cooperation on the Himalayas between the two nuclear-armed archrivals.

India and Pakistan share a fractious border, 60 years of enmity and the waters of the Indus River. Originating more than 17,000 feet above sea level in the Tibetan Plateau, the Indus crosses the hotly contested Himalayan Kashmir, fertilizing rich farmland in both India and Pakistan, before flowing into the Arabian Sea south of Karachi.

The river's flow has always been a source of tension, for a simple reason: Whoever controls the headwaters controls the river. Despite the Indus Water Treaty, which for more than 50 years has allowed the two countries to share the Indus and its five tributaries, control and access to water have remained a volatile issue. Disputes over hydroelectric dams, in particular, have made basic data sharing about the melting Himalayan glaciers a constant struggle, scientists from both countries say.

"When you talk about water data, it's very sensitive," said Pradeep Mool, a remote sensing specialist at the International Centre for Integrated Mountain Development (ICIMOD) in

Kathmandu. "There's so many disputed points where there's a glacier located, and it's very difficult for countries to get the information to each other. It takes a diplomatic dialogue."

Where intrigue flows with the water

Syed Iqbal Hasnain, a leading Indian glaciologist and senior fellow at the Stimson Center in Washington, D.C., added: "The issue is that nobody is sharing the low flows data, because if they share that data, they will be exposing their own intrigues into the water. If you look at the geopolitical implications of this glacier melt, there is so much potential for conflicts and accusations that 'You're stealing my water.' And all of these are nuclear power countries."

Yet the steady melting of low-elevation glaciers in the Himalayan mountain range makes cooperation critical. Without better sharing of real-time water flow information, Hasnain and others said, India and Pakistan will be ever more vulnerable to floods. In the long run, disputes can cripple national and local governments' abilities in both countries to manage what is expected to be a serious decrease in water availability.

"If they don't work together, both will suffer. Everybody will suffer, and there will be a situation that is beyond either's control," Hasnain said.

Dane McKinney, a professor of environmental engineering at the University of Texas, Austin, noted that water conflicts and secrecy over flow are hardly unique to Asia.

"Everywhere in the world, streamflow data is very closely guarded," he said. "It's one thing to know how much rain is flowing, but it's another thing to know how much flow. That water is used for economic and strategic reasons, so countries then feel it's part of their national security."

Yet the intertwined dependence of India, Pakistan, Bangladesh, China, Laos, Thailand, Myanmar, Cambodia and Vietnam on mutual river systems make South Asia uniquely fraught. Experts say the region is badly in need of of a new, holistic way of thinking on water resources management.

"Water is power in our countries," said Pravin Raj Maskey, a hydrologist with Nepal's Ministry of Irrigation. "From the India side, we find the hydrological data very secret, and that's in their national interest."

Can Finland end a deadly silence on floods?

Pakistan has been pressing for the release of data gathered by the Geological Survey of India on glacier melt, but much of it remains classified. According to the Indian media, the issue has been referred to the country's defense ministry, which is reviewing whether transparency of scientific research in the border area would compromise India's national security.

Meanwhile, India and Pakistan are hardly the only acrimonious players in the region. Meltwater from the Tibetan glaciers also supplies India and China, which fought a war over disputed Himalayan border territory in 1962. The search for water resources has been a persistent source of tension between the two countries, and both are exploring ways to harness the Himalayan melt for hydroelectric power projects.

"The source of the Indus is in China," Archana Chatterjee, regional program coordinator of the World Wildlife Fund in India, reminded participants at a mountain conference in Kathmandu recently who were criticizing Indian secrecy.

"It's undergoing a lot of mining activities and pressures," she said. "If the source is under so much pressure ... I think the three countries need to sit together, not just two countries."

Chinese scientists, meanwhile, turn the tables back on India. "Truly we are sharing," said Lizong Wu with the Chinese Academy of Science. "In this region, China was the first to complete a glacier inventory," he said, noting that it has been archived and is available for public download online. "India completed a glacier inventory, but where?"

Yet scientists and some policymakers in all of the Himalayan countries are working hard to end the cycle of hide-and-blame.

ICIMOD, based in Kathmandu, has made regional cooperation and the exchange of information among the eight countries in the Himalayan region a top priority. The common threat of climate change, some experts say, is actually starting to push parties to the table, making them more willing to cooperate.

Mandira Shrestha, a water resources specialist with ICIMOD, said the 2010 establishment of a regional flood information system in the Hindu Kush-Himalaya region has the potential to make significant strides. Funded by the government of Finland, the partnership of Bangladesh, Bhutan, China, India, Nepal and Pakistan is designed to foster timely exchanges of flood data, focusing on the Ganges-Brahmaputra-Meghna and Indus river basins.

At 21,000 feet, Siachin Glacier is considered the world's highest battlefield. Located in the disputed Kashmir region, the glacier feeds the Indus River and is surrounded by Indian and Pakistani troops. Scientific expeditions are closely guarded, as are glacier melt data. Photo courtesy of Sandia National Laboratories.

Shrestha noted that most of the Himalayan glacier lakes are in Tibet, while the impacts of floods, landslides and glacier lake outburst floods are primarily felt downstream. Floods account for 30 percent of all natural disasters in the Hindu Kush-Himalaya region.

Visa denial prolongs a lack of capacity

"Most of our river basins are transboundary rivers. There are no borders for rivers, and the impacts are shared between borders," she said. In addition to the need to encourage data sharing, Shrestha added, the lack of technical capacity in many of the affected countries poses an enormous problem. Without weather stations, for example, there is little data to share. "There's a lack of technical and human capacity, and the political will and regional cooperation is still emerging," she said.

Ghazanfar Ali, a glaciologist with Pakistan's Global Change Impact Study Center, noted that the country has over the past decade installed five glacier monitoring stations. But more are needed.

"If you can share data on a real-time basis, we may avoid a lot of damages due to floods," he said and called upon ICIMOD to help countries in the region develop their own technical skills.

Yet one of the biggest hurdles to cooperation, scientists in India and Pakistan say, is the not-so-simple act of getting into one another's countries. The denial of visas from both countries has become so routine that many now simply bypass both countries and organize conferences in neutral countries. Next month, ministers from the region will meet in Bhutan to lay out a blueprint for adapting to Himalayan glacier melt. Hasnain, meanwhile, is working to bring more than 100 scientists together in Nepal.

"If we bring 120 Indians to Pakistan or Pakistanis to India, we will have a visa issue, so we will do the workshop in Kathmandu," he said.

Yet with the climate threat looming, more and more activists are urging the two countries to deal with one another head-on. Saleem Ali, a professor of environmental studies at the University of Vermont who along with Mehra helped organize the youth conference in Lahore this year, said they made a conscious decision that the meeting must be held in Pakistan.

"We insisted that we wouldn't do it in Dubai or Nepal. That makes it a sideshow. Access is in itself a touchy issue, and you can't get all those poor Pakistani students to get to Kathmandu," Ali said. He argued that if the countries don't cooperate to find regional water management solutions, they will be signing death warrants for millions of their own citizens.

"Lives are at stake," Ali said. "It's a very serious human security issue. This is very serious business."

Oct. 26, 2011, ClimateWire, Lisa Friedman

What happens when the lake comes down the mountain?

The scruffy group of scientists had taken their first showers in more than a week after trekking the snow-capped Himalayan mountains, and were eager to tell officials in Kathmandu about the growing dangers they witnessed at Nepal's fastest-growing glacier lake.

But Andreas Schild, director-general of the International Centre for Integrated Mountain Development (ICIMOD), was not impressed. Lake Imja, he said, is low on Nepal's list of vulnerable lakes -- and he suggested it might be in greater danger of overflowing with scientists than with water.

In the 1960s, this massive lake in Nepal's Himalayan mountains was just a handful of small melt ponds. Now it threatens to wipe out everything in its path, including the popular trail to Mount Everest Base Camp. Photo courtesy of Daniel Byers.

"Be careful," Schild warned the stunned group of glaciologists, geologists and engineers working with the Mountain Institute, a Washington, D.C.-based conservation and research group that led the expedition with funding from the U.S. Agency for International Development. "If you are cocksure about your findings, remember that others are equally sure of their findings. Some think that there are areas that are more risky, but not as easy to access as Imja Lake."

The lake, a massive pool of concrete-gray waters in Nepal's Dudh Kosi Basin, barely existed a half-century ago. But as the Imja Glacier southeast of Mount Everest receded, the accumulating waters steadily swelled a handful of melt ponds that grew together to form Imja Tsho, or Imja Lake.

Perched at an altitude higher than 16,000 feet, and the size of about 200 football fields, Imja drains through a valley that traces the country's only trail to Mount Everest Base Camp. The glacier continues to lose about 35 meters of ice each year, and the lake has grown an average of half an acre each year.

If Imja were to burst in what is known as a glacier lake outburst flood, or GLOF, it could kill hundreds and perhaps thousands of people, the Mountain Institute scientists and others warn. It could also cripple the region's economy, sweeping away the Everest trail, which beckons 30,000 tourists each year, as well as the hundreds of tea houses and lodges whose owners' livelihoods depend on trekking traffic.

"At the moment, the lake looks stable, but we don't know how long it will be stable," said Ugan Manandhar, manager of the climate change team at the World Wildlife Fund's Nepal office. Nepal already has suffered 24 GLOFs, including one in 1985 that destroyed 14 bridges and a nearly completed hydroelectric project. If a flood from Imja took out the Everest trail, it could effectively eliminate the $350 million in tourist dollars that feeds Nepal's economy each year.

"If Imja becomes unsafe, not only the economy of that region will suffer but the whole country will be impacted," Manandhar said.

Where 'tipping points' are not just rhetoric

Over the years, dozens of scientists have made their way to Imja, following a well-worn trail from Lukla -- an airstrip town at an altitude of 9,800 feet that serves as the gateway to the Everest region -- up steep terrain through Sherpa villages and forests of fir and rhododendron, past colorful Tibetan prayer flags and stupas, spinning Buddhist prayer wheels along the way.

It can take about 10 days to trek to Imja, and that makes it one of the most accessible glacier lakes in the Himalayas.

Teiji Watanabe, a professor of environmental science at Hokkaido University in Japan, has been studying Imja Lake since the 1980s. Chatting in a Himalayan lodge a day after he descended from Imja in September, Watanabe recalled the first time he saw a picture of the lake.

"I knew it was very special. Like a holy something," he said. He felt that same rush of emotions on his first field visit. "Again, I felt a very ... something I cannot explain in English," he said. And, he added, "Compared to other places, it's much easier to research."

Yet the relative ease with which hardy scientists can access Imja also makes it a target of suspicion to some experts who say it's not overflowing -- just overstudied. In 2009, ICIMOD scientists conducted extensive field studies at Imja and two other potentially dangerous glacier lakes, and put Imja at the bottom of the list.

The study noted that while the lake is growing in volume, the "end-moraine complexes" -- dams that hold water in place -- are stable, and free-flowing water outlets serve to reduce pressure.

At the top of the dangerous list was Tsho Rolpa Lake, which threatens to burst through its unstable dam, destroying lives and livestock in Nepal's scenic Rolwaling Valley just south of the Tibetan border. Tsho Rolpa was the object of a partially successful $4 million attempt to lower the water levels and a failed experiment in installing an early warning system.

"Tsho Rolpa is the most dangerous lake, and it has to be a priority, but it's very difficult to access," said Pravin Raj Maskey, a hydrologist with Nepal's Ministry of Irrigation who joined the expedition.

Like Thulagi Lake, another vulnerable glacier lake in the Upper Marsyangdi River Basin that ICIMOD listed as second in vulnerability, Tsho Rolpa is not on a tourist route. That means in addition to the days or weeks it takes to hike up to the lakes, scientists must carry in all their food, supplies and research equipment. Imja, Maskey said, "is a place where scientists like to come, but it is not the first-priority place where they should be working. It is the third."

Local villagers also have a beef with the multitude of scientists who come to study Imja.

Scientists 'make people scared'

"So many scientists do global warming projects at Imja Lake," said Ang Nuru Sherpa, 44, a former Everest trekking guide who is building a lodge at the edge of Namche Bazaar. "They make people scared. That's not good," he said.

"They make their project and they forget it, just like that," said Nyima Tsering Sherpa, 31, who owns a trekking gear shop in the region. "Lots of people are scared of the GLOF, and other people say the scientists are the ones that bring the problems. They're just studying; they don't care. They bring the problems, but not the solutions."

Scientific expeditions to Lake Imja, like the one led by the Mountain Institute, are all too common, some experts and community members complain. Villagers say they want action, not more studies. Photo courtesy of Daniel Byers.

That, however, was precisely the problem that the Mountain Institute and the 30 glaciologists, engineers and social scientists from 15 countries who made the climb to Imja were trying to remedy. In what many villagers in the region described as an unprecedented collaboration, the scientists not only met with members of local communities in the town of Dingboche but trekked with them to Imja to observe it together.

"Local people are very tired of researchers who parachute in and never provide results to the local people," said Alton Byers, a mountain geographer who has spent decades working in Nepal and led the Mountain Institute's expedition.

Together, Byers said, they saw dangers at Imja Lake that have either been overlooked or have developed in the two years that have passed since ICIMOD researchers conducted field research. Not only had the volume of the lake grown, but the researchers found new ponds that were not there in 2009, as well as cracks and seepage in the moraine.

Watanabe, who only a few years ago wrote a report noting the lake's stability, said he left Imja worried. "The changes are getting more rapid," he said. "It's larger if you compare to the late 1980s, but even if you compare to three years ago, it's bigger." Watanabe said Imja may not be in immediate danger of flooding, but "10 years later, nobody knows. We really need to monitor it every year."

It remains unclear if that monitoring will happen or who will be in charge. ICIMOD scientists ended a two-day conference with the Mountain Institute scientists in Kathmandu saying they had heard nothing to change their position. Most remain lukewarm about acting at Imja, preferring to focus on Tsho Rolpa, which, they say, might not capture the attention of the international community but is more important locally.

"Both lakes are classified as dangerous. Depending on the resources, we have to monitor this, and depending on the resources, we have to do something about it," said Madhav Karki, deputy director-general of ICIMOD.

That concerns environmental activists, who note that the magnitude-6.9 earthquake that hit the Nepal-India border last month, causing landslides throughout the Himalayas, was a worrisome reminder that anything could set off dangerous changes at Imja.

"What trigger will it take?" Manandhar asked. "Just saying that Lake Imja is safe doesn't take away the vulnerability."

Oct. 26, 2011, ClimateWire, Lisa Friedman

Using the Himalayas as a laboratory to understand a dire new global threat

The Sherpa stew sloshed out of my bowl as the wooden table in our Himalayan lodge swayed back and forth. Someone yelled "Earthquake!" and I bolted for the door with other panicked trekkers, tumbling into the chilly mountain night.

Farther up the mountain, the international group of glaciologists and engineers I was climbing to meet were huddled outside their own lodge in the village of Lobuche below Everest Base Camp. At higher than 16,000 feet in the dark, they could hear -- but, terrifyingly, not see -- an avalanche of snow falling from one of the highest peaks in the world.

Scientists from 15 countries led by the Mountain Institute trekked to Lake Imja, a flood-prone glacier lake in the Himalayas, to study the dangers it poses as well as gain a better understanding of glacier lakes in their own countries. Photo courtesy of Daniel Byers.

They were just a day's hike from Imja Lake, a sweeping body of gray water along the Everest trail that had swelled from a few ponds in just half a century as the seemingly indestructible glacier above it steadily melted away. Many of them experts in a phenomenon known as glacier lake outburst flooding, or GLOFs, the scientists knew a magnitude-6.8 temblor like the one that struck that night had the power to make a fragile lake empty itself, destroying everything in its path.

Some had seen it before in Peru's Cordillera Blanca range, when a 1970 earthquake shook a section of glacier off Mount Huascarán. The glacier plummeted thousands of feet into the Rio Santa Valley, collecting boulders as it fell to overflow the banks of the Rio Santa and kill more than 10,000 people in the towns below.

"It just came down the valley, a massive ice rock that just created a huge, gigantic avalanche. That one avalanche killed around 10,000 people. Imagine the size of it," said Jorge Recharte, director of the Mountain Institute's South America programs. "Mountains are fragile," he said. "It's gravity acting, and even though it seems like rocks are well set in the mountains, you're in a vertical landscape, and earthquakes just trigger instability."

Recharte was one of the 30 experts I met in the Khumbu mountain range last month who, under a program funded by the U.S. Agency for International Development, were trying to marry the decades-long experience of the Andes with Nepal's needs. Hailing as well from Japan, Bhutan, Pakistan, China, Tajikistan, Kyrgyzstan, Uzbekistan, Chile and Bolivia, the scientists also hoped to develop a global understanding of the new threat that melting glaciers are delivering to all their countries.

"This is almost unprecedented in human history," said Alton Byers, science and research director at the Mountain Institute, who organized the expedition.

"We have no real frame of reference for glacier lake outburst floods," he said, noting that the rate of glacier melt brought about by climate change is fundamentally changing the need to understand disaster risk management in different parts of the world. "This is all new, and suddenly we're being smacked in the face with something we had never had to deal with before."

Questioning the conventional wisdom

Peru, though, actually does have solid experience with the type of devastating floods that can occur when the dam containing a glacier lake fails. The tropical Andes has been susceptible to the problem since the 1940s. Learning from tragedy, Peru has over the past half-century successfully managed 34 lakes, drilling tunnels or channels to slowly siphon out water and prevent future flooding.

Much of that work was overseen by Cesar Portocarrero, the head of the glaciology department at Peru's national water agency. A civil engineer by training, Portocarrero started to work with dangerous lakes in the 1970s because, he said, "the glaciers were right in front of me." By the 1980s, he said, "I started to see the glaciers were retreating faster than before."

The question the Mountain Institute set out to answer was whether Portocarrero and his team could use their experience to help Nepal lower Imja Lake.

If Imja bursts, it could destroy dozens of villages along the Everest trail as well as the trail itself, which brings in badly needed tourist dollars to Nepal. But the Nepali government has become deeply suspicious of major engineering endeavors -- and with good reason. In 1995, Nepal and European donors installed a siphon at Tsho Rolpa, the country's largest glacier lake, with the intent of lowering it 20 meters. About 11 years and millions of dollars over budget later, they had managed to siphon away only 3 meters.

But the engineers who went up to the Khumbu last month weren't put off by the numbers. Byers, for one, said that while flying or paying porters to carry pipes and other supplies 16,000 feet up in the mountains would present a unique challenge, the mechanical problems are not insurmountable.

"Based on one experience which has resulted in a conventional wisdom that says it's impossible to do engineering, we don't accept that," he said. "We don't agree that's necessarily gospel." Added Portocarrero, "I am a civil engineer like many in the world, but I know about this kind of work, and I can help."

The real question, Byers, Portocarrero and others said once they had spent time in the Khumbu, was whether communities living downstream of Imja want that help.

The scientists meet the villagers

The group did something no scientists have ever done in the Khumbu: They worked with a local community group from the village of Dingboche to survey the glacier lake and discuss what recent findings may mean for downstream villages. That appeared to have alleviated a good deal of frustration among locals who said they are sick of researchers who leave Imja with notebooks full of data but not a word to those who could lose their lives and livelihoods if a major flood struck.

The scientists and development experts, on the other hand, emerged from the experience with more questions than answers. Many said they left with the distinct impression that communities were simply waiting for foreigners to protect them, and pay for it. They saw an absence of community involvement and civil infrastructure, as well as government neglect.

"If we can't find a partner, we're not going to succeed, so there's no point in starting work here," said John Furlow, a climate change specialist at USAID who accompanied the group. He pointed to black rubber pipes snaking out of each mountain home and lodge toward the river, and said it suggested an every-family-for-itself system that could make finding a partner in the region difficult. And, he noted, neither the International Centre for Integrated Mountain Development, an international mountain research group based in Kathmandu, nor the Nepali government appeared enthusiastic about Imja.

"I want to make sure that any engineering is based in a social structure that's acceptable," Furlow said.

Upon my return to Kathmandu, though, nonprofit groups that do extensive work in the region told me the Khumbu most certainly has a civic structure. Villagers routinely trek miles up and down the valleys to public hearings -- though, noted Ugan Manandhar, manager of the climate change team at the World Wildlife Fund's Nepal office, "When you start a meeting at 10 o'clock, it will never start at 10 o'clock. It will start at 2 o'clock."

The pipes, Manandhar said, might not look like an organized system, but they are, and villagers pay for their water use. He described long-standing committees that successfully lobby for -- as well as pay for and maintain -- mini-hydropower plants in remote villages off the Everest trail. He and representatives of other Kathmandu non-governmental organizations suggested that the U.S.-funded expedition should have done more legwork to understand the region, or to reach out to different groups that could easily answer questions.

Forming a global glacier lakes partnership

While confusion over Imja and how best to approach downstream communities to determine what level of protecting they want from glacier lake flooding persists, it also is clear that a potentially groundbreaking partnership is on the horizon.

Talking over a plate of french fries at a Kathmandu hotel after three weeks of tea and steamed Nepali dumplings on the trail, Byers began to speak of Imja more as a laboratory for global understanding of glacier lakes -- not just in the Himalayas, but also in Central Asia and Latin America.

"In all cases, all these countries are mountainous. All of them are experiencing a warming trend and the enlargement of glacier lakes. And all have governments, with the exception of one or two, that are probably not equipped to handle a GLOF," he said.

Over the next five years, Byers said, he wants to see communities in the Himalayas receive the attention they need to decide if an engineering solution to Imja is something they want. But he also outlined a vision for a global partnership where scientists in other parts of the world can go to learn how to work with glacier lake communities.

"We're going to do prevention and mitigation of hazards. It's going to save lives, and it's going to operate in a dozen countries worldwide," he said. The endeavor could also make way for more scientists to put down the satellite data and hike their way up mountains to see the glacier lakes they study for themselves.

"I see a new generation of mountain geographers who focus on the culture and environs of mountains," Byers said. "It's what I call the climber-scientists. We have a new generation of scientists who are hungry to get into the field, and we need to combine the best of muddy boots research with the best science can give us."

Oct. 27, 2011, ClimateWire, Lisa Friedman

Himalayans find monsoon changes 'very bad for business'

KATHMANDU, Nepal -- Rain pummels the chaotic streets here. Cars, rickshaws and motorbikes pack the roads, swerving around the occasional cow. The unrelenting blare of honking that is the music of this city seems to amplify with every falling drop.

As farm production in Nepal declines, the men increasingly migrate to India for seasonal work. That leaves the women to take on hard labor to help feed their families. Photo courtesy of Oxfam.

Dipak Khan looks outside his jewelry shop in Thamel, where vendors hawk yak wool blankets and wallets decorated with Buddha eyes. It is the first day of Dashain, the Hindu festival that marks the end of the long monsoon season. A group of tourists ducks under a doorway for cover from the downpour. Khan is worried.

"This is the global warming," Khan says with conviction. "The rains should not come this late. It hurts everything. The tourists do not want to walk around in this. It is very bad for business."

Climate change cannot be linked to any one weather event. But scientists, environmental activists and Nepalis themselves say the monsoon season so critical to agriculture is undoubtedly changing. Whether driven by cyclic changes, rising global temperatures or both, they say, the new patterns shaking up the June-through-September South Asian monsoon season are hurting crop yields and exacerbating already-existing problems of poverty and failed development.

The breathtaking Himalayas and the fate of their glaciers may capture the majority of climate change attention in Nepal. But activists point out that from the fertile plains to the overcrowded capital of Kathmandu, the landlocked country sandwiched between China and India faces widespread threats to crop production, livestock and water availability.

The national flower tries to adapt

"When the issue of climate change comes here, people understand about the glaciers and the Himalayas. It is true that the Himalayas are melting, but when you come inside Nepal, you see the other impacts," said Manjeet Dhakal, director of Clean Energy Nepal.

Farmers in the plains are seeing more sedimentation and land erosion, higher river flooding and even unusual blossoming times of the rhododendron, Nepal's national flower. Just a few years ago, winter droughts and a delayed summer monsoon left agricultural land uncultivated. Oxfam called the 2008-2009 drought one of the worst on record, with 3.4 million people estimated to need food assistance.

This year, Nepal is seeing the highest rate of rainfall in 30 years.

"The monsoon is so unreliable, and the farmers who depend on it for agriculture are getting the brunt," said Shubash Lohani, deputy director of WWF's Eastern Himalaya program. Because the country's irrigation system is not well developed, he said, people rely almost completely on rainfall for 80 percent of the country's agricultural needs.

In Kathmandu, meanwhile, water demand is exploding. The population rate has tripled in the past 20 years to about 4 million people. Most of the city's drinking water comes from the Bagmati River system, but officials say it is poorly managed -- used as a dumping site in some areas -- and can only meet half the city's demand.

Tunnel vision

"Kathmandu in particular is expanding very rapidly. The whole water balance is being screwed up, and that is fundamental. Now, on top of that, with climate change we are going to have erratic rain patterns," said Bhushan Tuladhar, coordinator of Climate Change Network Nepal and a technical adviser on water for U.N. Habitat Nepal.

Since 2007, the Nepal government has worked hard to develop a strong presence at the U.N. climate talks and to build awareness inside the country of the threats. Recently, the prime minister developed a climate change council aimed at integrating knowledge about the impacts of rising global temperatures with local planning.

Yet in places like Kathmandu, according to Tuladhar, that's a serious challenge. Plans are currently under way to divert water to Kathmandu through a 28-kilometer tunnel from the Melamchi River in a neighboring valley. The Melamchi is a tributary of the larger Indravati River basin, fed in part by the Himalayan glaciers.

"If the glaciers are melting very fast, when we dig that tunnel, Melamchi may not have as much water as we thought," Tuladhar said, adding that he hopes a growing understanding of climate change in Nepal will somehow provide an opportunity for policymakers to develop better water planning methods.

"It highlights a lot of issues that we should be taking care of anyway," he said.

Oct. 27, 2011, ClimateWire, Lisa Friedman

Himalayan alchemy -- a 'diamond' grows from garbage

KATHMANDU, Nepal -- Cigarette packs, candy wrappers, plastic water bottles and the occasional shoe litter the narrow streets here and clog the gutters. Sanu Kaji Shrestha looks around and sees gems.

From a shed in a quiet courtyard a few hundred yards from the chaos of the city streets, Shrestha tries to turn Kathmandu garbage into its energy future. Everything from seaweed to sawdust makes its way into his Foundation for Sustainable Technologies, coming out the other end a "briquette" of low-smoke, long-burning fuel that he believes could change the lives of the poor in Nepal and elsewhere.

"Every bit of grass has energy," he proclaims with a broad smile, showing off the fuel bricks he has made from dried leaves, kitchen scraps and even date pits from the Middle East. "I just make energy from the waste material that we produce."

The recycler: Sanu Kaji Shrestha holds a fuel "briquette" made from pulped, compressed garbage. Photo by Lisa Friedman.

About 3 billion people across the globe cook by burning biomass like wood, crude coal or animal dung. The World Health Organization estimates that toxic smoke from such unsafe cookstoves is responsible for nearly 2 million premature deaths every year, and contributes to everything from low birth weight to respiratory infections.

Groups like the U.N. Foundation have sought to change that trend. Through the Global Alliance for Clean Cookstoves, the U.N. Foundation, along with the Clinton Global Initiative and others, is working to see 100 million homes in developing countries adopt cleaner cooking alternatives by 2020.

Yet in Nepal, where only 10 percent of households are connected to the power grid, Shrestha said, convincing people to change their way of cooking is no easy feat.

Shreshtha was a part-time inventor even before he retired from the World Bank in 2001. His first creation was a small solar cooker. Having seen one at an exhibition, he decided in 1995 to make his own after one of Kathmandu's kerosene shortages.

Funding from Rotary clubs

His wife, however, would have nothing to do with it.

"Solar cooking habit is not the Nepali habit. It's very difficult to cook dal bhat," he said, referring to the lentil and rice dish that is a staple of nearly every Nepali meal.

"I had to cook it for her myself to convince her it would taste the same," Shrestha said. He did the same for his neighbors. "That is the main thing, not changing the food habit."

A few years later, the idea for fuel briquettes was born when Kathmandu's drains became blocked in a major flood. The culprit: wet cardboard boxes clogging the pipes. Shrestha took some, mashed them into a pulp and molded it with a tin can.

"This is my diamond," he said, holding up that first lump of grayish-brown hardened pulp. Since then, he has worked constantly to refine the briquettes, mashing them first with a lever press that required three people before coming up with a device that a single person could operate. The goal, he said, is to develop a process that people, particularly people in poor and rural areas, can do easily on their own. Then he serves a glass of sweet tea, cooked over a small briquette fire.

As with solar cookstoves, he said, convincing the public to use cleaner-burning and longer-lasting waste fuel will take time despite the benefits. But, he said, "Once we show people food will take less time and taste as good, then they will accept it."

Though his work has been recognized by the Nepal Academy of Science and Technology, the British Council and U.S. EPA, Shrestha's foundation receives little outside funding beyond support from some Rotary clubs in the United States. With that, though, he has traveled from Cambodia to Afghanistan to train villages on ways to segregate waste and use it wisely. He wants to see the movement spread.

Said Shrestha, "People used to say, 'Water for all.' That was the global vision. I say, 'Why not fuel for all?' We have the full resources."

The Rising Nepal, Bhimsen Thapaliya

Rumour On Himalayas

Link to Story.

When a team of scientists from 15 countries including Nepal made an observation tour of the Imja glacial lake (5,023 metres) in the Everest region early last month, they were alerted by the sheer size of the lake that has increased over the decades. Though an inspection visit is hardly sufficient for drawing scientific data, members of the tour organised by The Mountain Institute pointed out that things may become quite precarious in a decade or so though the lake is quite stable at the moment.

The water is already seeping through the moraine or the natural dam that holds the water, and the wall may weaken over the years as the lake water volume keeps rising. The worst may come in case of a major earthquake, said Dr. Alton Byers of The Mountain Institute.

Accompanying the scientists' team was a US journalist Lisa Friedman who writes on climate issues for ClimateWire magazine. The magazine has published Friedman's articles on climate impacts on the Himalayas, Nepal and the surrounding region. She reports that the mountains are vulnerable with the possibility of glacial lakes bursting but also points out those things are being blown out of proportion in the absence of solid scientific data.

Her report centres around the myths that glacial melts will eventually dry up the rivers, the snow-covered mountains will turn bare in decades and that Himalayan ice melts are taking place at the highest rate in the world.

Gathering expert views, Friedman reports that major rivers originating in the Himalayas will not dry up as predicted because the role of glacial melt in their flow is minimal. They are mainly fed by the rains. The Indus and Brahmaputra have relatively higher content of water coming from the Himalayan ice melt but will not see a major impact on their flow from the glacial melting.

Critical gap in scientific data on the impact of global warming on the Himalayas was well reflected in the fourth assessment report of the International Panel on Climate Change (IPCC). The report stated that the Himalayan ice will melt away completely in a few decades. IPCC chairman Rajendra Pachauri had to apologise, admitting that the prediction was erroneous.

Participating in the Imja expedition was Cesar Portocarrero, the head of the glaciology department at Peru's National Water Agency who has good experience on disasters related to bursts of glacial lakes in the Andes mountains. Sharing his Andean experience, Portocarrero said that steps should be taken to siphon the water off to lower the lake water level. The water could be used to generate hydropower but such a project will not succeed unless local communities are actively involved.

One should learn from the Tsho-Rolpa lake where four million dollars were spent to drain out the water and install an early warning system. Now the project is in tatters.

In her report, Friedman says that the local people in the Khumbu region are fed up with scientists visiting Imja and returning with dooms-day predictions. She interviewed a local Sherpa businessman who said that spreading baseless rumours about looming catastrophes on the Everest trails will negatively affect tourism and his business.

Sept. 26, 2011, All Headline News, Anil Giri

U.S. offers help for dangerous Himalayan lake

An Assessment to the Himalayan Glacial

Several United States agencies have offered Nepal help and a possible solution to a potentially dangerous lake formed in the Himalayas by melting glaciers.
The U.S. State Department, USAID, the Mountain Institute and the U.S. National Science Foundation are sponsoring a month-long trek to Lake Imja, a recently-formed glacial lake at an altitude of 5,010 meters near Mt. Everest.

During the trek, an international team of more than 30 scientists, engineers, photographers and journalists will evaluate the danger of Imja, and determine how to control it so it can supply fresh water safely and reliably to downstream communities for drinking, irrigation, and the generation of electricity.

A 2009 study described this lake of melt water as one of the fastest-growing in the Himalayas. Holding an estimated water volume of 35 million cubic meters and growing over the decades, scientists have put Imja on the list of glacial lakes with potential risk of outburst.

Scientists who trekked for over a week to reach the lake indicated no immediate danger from the lake but suggested steps to reduce water level to minimize future risks.

Immediate measures to lower the water level, such as siphoning, are important because the volume is growing, said Dr. Alton Byers of The Mountain Institute, the organizer of the Imja expedition.

"In an event of an earthquake, potential risk is higher," said Byers.

Researchers participating in the study are from Nepal, Bhutan, Pakistan, Tajikistan, Uzbekistan, Kyrgyzstan, China, Peru, Bolivia, Japan, the U.S. and Europe.