This Changing World

Promoting science-based, community-driven approaches to climate change adaptation in glaciated mountain ranges: HiMAP

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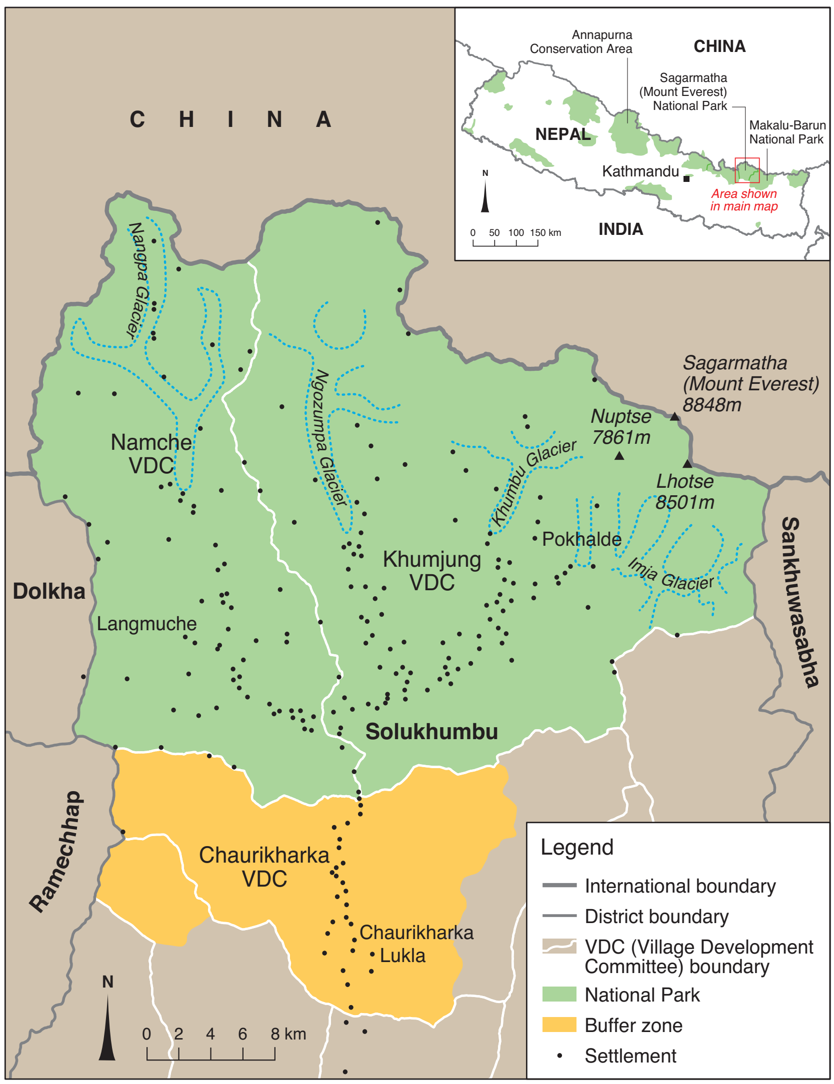
ABSTRACT: Glaciated mountains remain among the most under-studied regions in the world from a physical, social and climate change perspective, which complicates the development of appropriate adaptation and hazard mitigation approaches. The goal of the High Mountains Adaptation Partnership (HiMAP) project is to create conditions necessary for all the stakeholders who live in, or are dependent upon glacial watersheds, to become more resilient to the impacts of climate change. This article documents the origins, establishment, implementation and experiences of the HiMAP in the Sagarmatha (Mount Everest) National Park and Buffer Zone in Khumbu, Nepal, from its formation in March 2012 up to August 2014. Regardless of the Partnership's success, it is clear that glacier-dominated areas of the world will continue to pose unique challenges to highland and downstream communities as they adapt to the impacts of global climate change, particularly in terms of the increasing threats of glacial lake outburst floods. Given the critical importance of glaciated landscapes to the millions of people living in cities and communities downstream, this article demonstrates that interdisciplinary climate change research approaches and applied field projects are necessary for climate change adaptation initiatives to be effective.

Figure 1: *Nepal: location of places and features mentioned in the text.*



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Introduction

Glacier-dominated mountains play a major role in providing water to large numbers of people, especially in the Himalayas (Barnett *et al.,* 2005; Byers, 2007a; Viviroli *et al.,* 2007; Armstrong, 2010). Here, some 1.4 billion people living downstream of the Himalayas depend on water from the Indus, Ganges, Brahmaputra, Yangtze and Yellow Rivers (Immerzeel *et al.,* 2010). Continued and increasing glacier melting may initially increase runoff in some regions, but the lack of a glacial buffer will ultimately cause decreased reliability of dry season streamflow (Bradley *et al.,* 2006). This will, in turn, affect future water supplies, hydropower, agricultural productivity and ecosystems, and significantly impact on local livelihoods (Bradley *et al.,* 2006; Carey *et al.,* 2014). These glacial-dominated areas pose unique challenges to downstream communities as they adapt to recent and continuing global climate change, particularly the increased threats from glacial lake outburst floods (GLOFs) (Richardson and Reynolds, 2000; Huggel *et al.,* 2003; Carey, 2005; ICIMOD, 2011). They also remain among the most under-studied regions in the world, from a physical, social and climate change perspective (Armstrong, 2010; McDowell *et al.*, 2014; Carey *et al.,* 2014). Given the critical importance of the world's glaciated landscapes, it is increasingly argued that interdisciplinary climate change research and applied field projects – both of which span the natural, social and engineering sciences – are urgently needed (Carey *et al.,* 2014).

Created in 2012, the High Mountains Adaptation Partnership (HiMAP) focuses on remote, high-altitude mountain ecosystems and communities. Its goal is to create conditions necessary for all stakeholders who live in, and are dependent upon, glacial watersheds (including local communities, government agencies and downstream populations), to become more resilient to the impacts of climate change. This article documents the origins, establishment and implementation of the HiMAP in the Sagarmatha (Mount Everest) National Park and Buffer Zone (hereafter called Sagarmatha NPBZ) situated in Khumbu, Nepal (Figure 1). Covering an area of 1113km^2, the Park is bounded by mountain peaks in excess of 6000m, including the world's highest, Mount Everest, at 8848m (Byers, 2005). Khumbu is the traditional home of the Sherpa people, formerly agro-pastoralists and traders, whose economies are now dominated by the adventure tourism trade (trekking and climbing). The region is particularly vulnerable to climate change impacts because of its extreme topography, remoteness, lack of transport facilities and tourist-driven economy.

Glaciers and contemporary impacts of climate change

Glaciers have been called one of the most dramatic indicators of climate change, particularly when using methods like repeat photography. When such photographs are supplemented with remote sensing time-lapse images, they allow the documentation of contemporary glacial processes such as recession, meltwater pond formation and the creation of new glacial lakes.

One source of historic photographs is the archives of early 'climber-scientists', who were often attached to the mountaineering expeditions that began frequenting the Khumbu region in the early 1950s. In 1953, for example, Sir Charles Evans was Deputy Director of the British expedition that put the first humans on the summit of Mount Everest: Edmund Hillary and Tenzing Norgay. After the success of the expedition, Evans stayed on for six months conducting glacier research in the upper Imja Khola region (Byers, 2010a). In 1956,

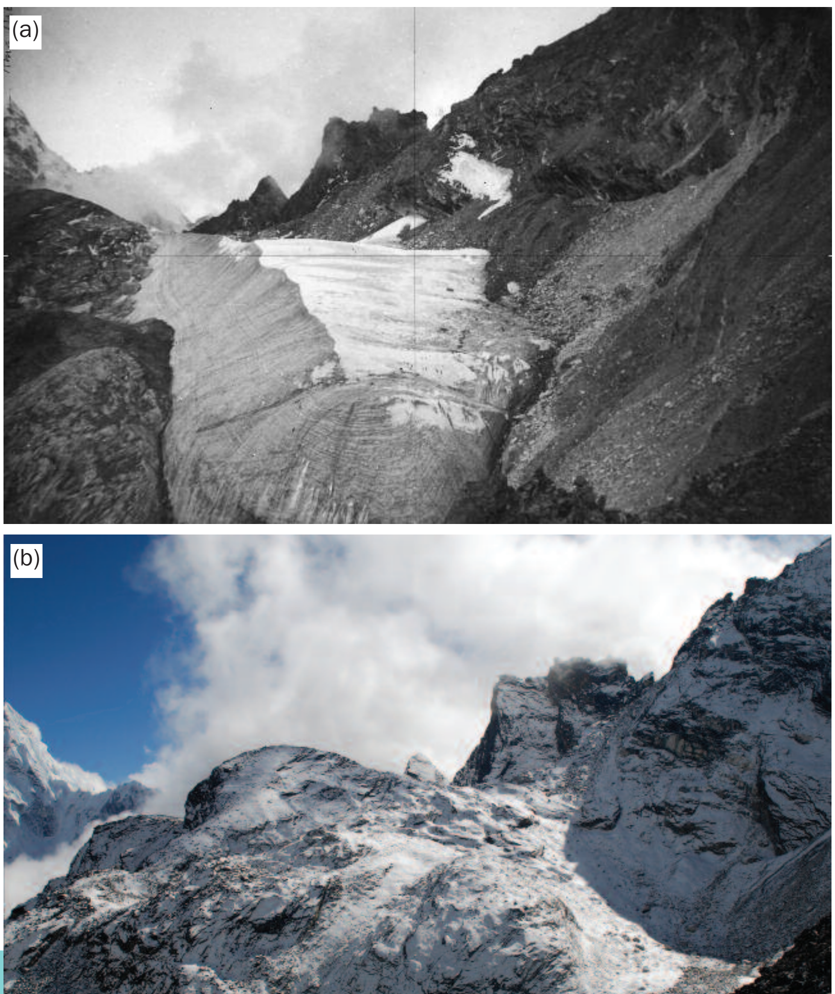

Figure 2: *The extent of Pokhalde Glacier near Kongma La in: (a) 1956, and (b) 2007. Photos: © (a) Fritz Müller (courtesy of Jack D. Ives), (b) Alton C. Byers.*

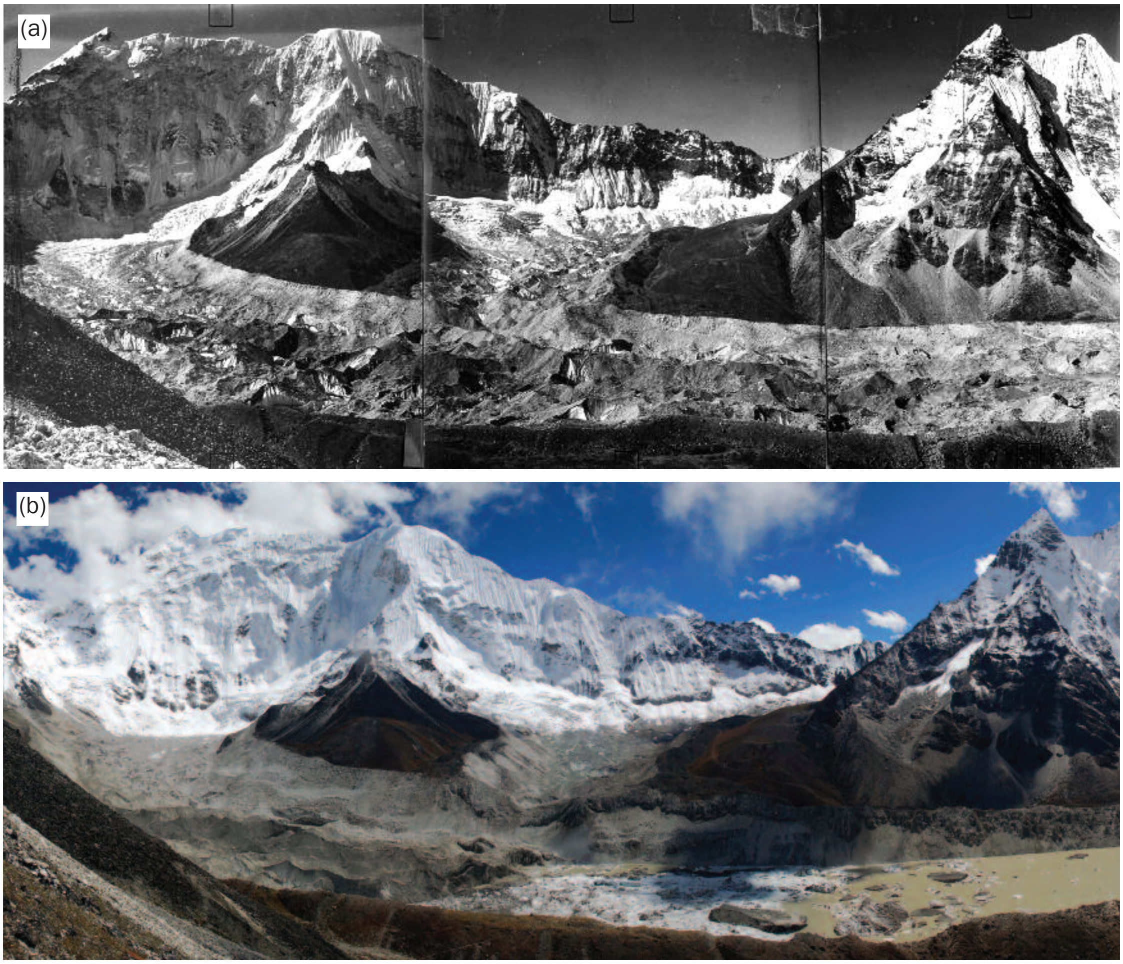

Figure 3: *Imja Glacier: (a) as seen in 1956; by 2012 (b) a lake had formed. Photos: © (a) Erwin Schneider (courtesy of the Association of Comparative Alpine Research, Munich. Archives of Alton C. Byers), and (b) Alton C. Byers.*

following the successful climb of Everest by the Swiss, the Swiss-Canadian glaciologist, Fritz Müller, then spent nine months in the region above 5000m, conducting glacier research with a team of Sherpa assistants (Müller, 1959). Starting in 1956, the Austrian climber-cartographer Erwin Schneider began a terrestrial photogrammetric survey of the Mount Everest region with the objective of producing a 1:125,000 scale map (Finsterwalder, 1987). All three of these climber-scientists took thousands of photographs of the glaciers and 'alpine' landscapes; the location of hundreds of these photographs was identified and repeat images were captured in 2007 and 2008 (Byers, 2007b, 2010a,b, 2013a,b). The field checking and photographing of features that are of particular interest is now repeated each year.

Comparing the historic photographs with contemporary ones offers a unique window into the past, and has enabled a qualitative assessment of the changes in glacial ice that had occurred in the interim. The most dramatic changes observed suggest that, since 1956, the following had occurred:

- Hundreds of small (<0.5km^2), clean glaciers (C-Type) at lower altitudes (5200m) had either disappeared entirely or significantly reduced in size. For example, the Pokhalde Glacier near Kongma La (Figure 2).
- North-facing clean glaciers and ice fields at higher altitudes (e.g. 6000m) had ascended considerably and lost significant mass, but appeared to be temporarily stable due to the year-round freezing temperatures found there.
- South-facing clean ice, including the ice pinnacles below the Khumbu Icefall and various parts of Everest, Nuptse and Lhotse, was either gone or in a state of rapid recession.
- New and potentially dangerous glacial lakes, which were debris-covered glaciers (D-Type) in the 1950s, had formed in the interim. For example, Imja Lake – see Figure 3.
- Most of the debris-covered, D-Type glaciers had experienced considerable ablation and the formation of new meltwater ponds. Examples include the Khumbu and Ngozumpa glaciers, with the latter replicating the early stages of lake formation at Imja (glacial) Lake.

Differences in glacier slope, aspect, debris cover and altitude appeared to be the major variables contributing to the heterogeneous changes found among glaciers and glacial lakes within the

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Khumbu (Hambrey *et al.,* 2008; Kargel *et al.,* 2012). The findings did not support a number of popular claims being made at the time about the rate of glacial recession, such as the retreat of the Khumbu glacier by >5km since 1953 (Walters, 2002); nor that rapidly melting glaciers threatened death to millions by making substantial areas uninhabitable (Walters, 2002); nor internet reports of a GLOF near Kunde in 2008 (Byers, 2007b); nor predictions that all Himalayan glaciers would disappear by 2035 (Cruz *et al*., 2007). The repeated photographing of receding glaciers and changing alpine landscapes were among the first of their kind from the Everest region (Nepal side). These images were displayed to international audiences in photo exhibits at Everest basecamp and in cities across Europe and the USA in 2008–09 (see ICIMOD).

Of particular interest to both the public and scientific community alike was the dramatic formation of new glacial lakes since the 1960s. As many of the larger glaciers have melted in the Himalayas, 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 GLOFs. 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 waves caused 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 destruction of valuable farmland and infrastructure (e.g. hydroelectric facilities, roads, bridges). In 1985, the Langmoche outburst in the Sagarmatha NPBZ, Nepal, destroyed the Thami hydroelectric facility, hundreds of hectares of cropland and dozens of bridges downstream (Vuichard and Zimmerman, 1986). The 1998 outburst of the Sabai Tso in the Hinku Valley, Makalu-Barun National Park, Nepal, destroyed trails and seasonal settlements for 100km downstream (Cox, 1999; Osti and Egashira, 2009) – damage that is still visible in satellite images taken over a decade after the event.

Figure 4: *Climber-scientists carry out a ground penetrating radar (GPR) survey at Imja Lake, May 2012. Photo: © Alton C. Byers.*

Field-based knowledge exchange: the prelude to the HiMAP

Although experience in reducing the risk of GLOFs through the lowering of water levels or other mechanisms is limited in Nepal (Bajracharya *et al.,* 2007), Peruvian engineers have been controlling dangerous glacial lakes for more than 70 years (Carey, 2010). In the interests of sharing this knowledge more widely, in September 2011, The Mountain Institute hosted the 'Andean-Asian Mountains Global Knowledge Exchange on Glaciers, Glacial lakes, Water and Hazard Management' in the Mount Everest region of Nepal (The Mountain Institute, 2011). Rather than limit activities to a conference hall in Kathmandu, this 'mobile workshop' took place over an 18-day period in the Sagarmatha NPBZ. Over the course of the 250km trek from the Lukla airstrip to Imja glacial lake, 35 scientists from 15 different countries (including four from Peru) related their experiences on glacial lakes and hazards, GLOF risk reduction methods, freshwater supply and the human dimensions of climate change and adaptation. 'South-south collaboration' was promoted by including, for the first time in Nepal, Peruvian engineers with decades of experience in reducing the risk of dangerous glacial lakes in the Cordillera Blanca region of Peru. Local community members joined the workshop at Imja Lake to share their knowledge of the lake's history of growth, expansion and prospective dangers since it first started forming in the 1960s. The opportunity to study first-hand the contemporary impacts of climate change on high altitude environments and peoples was unprecedented. Workshop participants proposed that a 'High Mountain Glacial Watershed Program' be established, one that would focus specifically on glacial lake study and risk reduction and climate change adaptation, as well as carry out the promotion of field research among young scientists.

The High Mountains Adaptation Partnership

In March 2012, the High Mountains Adaptation Partnership (HiMAP) was officially formed with funding from the US Agency for International Development (USAID). HiMAP is designed to strengthen the scientific, social and institutional capacity for climate change adaptation and resilient development, as well as disaster risk mitigation and management of potentially dangerous glacial lakes and other climate-related disasters. The Partnership has attempted to do so through a series of inter-related activities. The first involves fostering the next generation of mountain-scientists and development practitioners through competitive 'climber-scientist' small grants; the second, developing rapid reconnaissance field methods for the study of potentially dangerous glacial lakes, including the modeling of downstream flood impacts and risk reduction engineering strategies; the third requires the development of climate change adaptation mechanisms for local communities; and the fourth involves building a global community of practice for high-mountain glacial watershed technical analysis, adaptation and climate-smart development.

Climber-scientist small grants programme

The climber-scientist competitive grant programme provides field-based, hands-on research opportunities to scientists and practitioners working in high mountain regions. Particular focus is placed on the generation of new knowledge regarding the impacts of climate change, interaction between highland and lowland communities, and methods for protecting fragile alpine ecosystems. The grant programme is particularly interested in funding applied research projects that: (a) encourage the systematic use of field work to support and augment remote sensing technologies, (b) assist mountain communities in adapting to climate change and (c) enhance the development of the next generation of high mountain physical and social scientists, including those with little climbing experience. It is founded on the belief that solutions to many of the challenges presented by climate change today will demand the systematic blending of the best of modern-day technologies with traditional, on-the-ground, field methods, including the active participation of local communities.

A glacial lake rapid reconnaissance approach

Compared to remote sensing analyses, field-based studies of glaciers and glacial lakes are relatively rare in the Himalayas (Byers *et al.,* 2013). This is most likely related to popular perceptions regarding the high cost of remote-area research, coupled with the high altitudes and extreme environments of the glaciated world, which result in difficult working conditions. Arguing that the best understandings of contemporary climate change impacts can only come from the systematic use of both laboratory and field techniques, HiMAP established the 'Glacial Lake Rapid Reconnaissance Team' in May 2012 (McKinney *et al.,* 2012). To date, the Team has completed five field expeditions to Imja Lake in the Sagarmatha NPBZ, the Makalu-Barun National Park and the Annapurna Conservation Area of Nepal (Figure 1). The purpose of these expeditions and follow-on analyses has been to quantify the risk of a GLOF from Imja Lake, the potential risk to downstream communities and possible remedial measures to reduce that risk to an acceptable level. The studies included ground penetrating radar (GPR) surveys of the terminal moraine and the Imja Glacier, a sonar bathymetric survey of the lake itself and computer modelling of a potential GLOF from Imja Lake with consequent downstream flooding.

In order to better understand the structure of Imja-Lhotse Shar glacier in the proximity of the eastern end of Imja Lake, GPR surveys were conducted in May and September of 2012 using a custom-built, low-frequency, short-pulse, ground-based radar system (Somos-Valenzuela *et al.,* 2014) (Figure 4). The GPR surveys were performed across the glacier from north to south, over most of the terminal moraine complex and around both sides of the lake outlet. Results show that glacier thickness varies from 40 to 60m near the lateral moraines of the glacier to over 200m in the centre. GPR surveys were also made at the western end of the lake in the moraine region. The results of the surveys show that there is extensive ice present in the core of the terminal moraine complex at Imja Lake, with the thickest ice near the western end on the north side of the lake's outlet. The depth of mixed debris and ice in the western moraine end of the lake was, however, difficult to determine from the GPR results.

Figure 5: *The bathymetric survey of Imja Lake, September 2012. Photo: © Chris Rainier.*

Figure 6: *Imja Lake glacier terminus: (a) May 2012, and (b) September 2012. Photos: © Daene McKinney.*

A bathymetric survey of Imja Lake was conducted in September 2012 using a sonar unit mounted on an inflatable raft (Figure 5). Several transects were made around the lake with the sonar unit measuring lake depth. During the survey, large icebergs covered the eastern end of the lake, blocking much of the access to that area. Nevertheless, the results suggest that the maximum depth of the lake has increased from 98 to 116m between 2002 and 2012, and the estimated volume from 35 million m^3 to 61.6 million m^3 during this period (Somos-Valenzuela *et al.,* 2014). Most of the expansion of Imja Lake in recent years has taken place in the glacier terminus/lake interface to the east, where more than 200m of glacial ice has been lost in recent years (see Figures 4 and 5). The decadal average rate of loss is 53m/yr compared to previous estimates of 34m/yr. The result of the GPR and bathymetric surveys make it clear that the ice of the glacier is significantly deeper than the lake and that the ice probably extends under the lake. The result of this is that the lake will continue to deepen in the future.

A hydraulic simulation model was developed to assess the impact of a potential GLOF from Imja Lake on downstream communities. Implications of proposed GLOF risk reduction alternatives, including one suggested by local community members, were assessed. Results of the modeling illustrate three alternatives that offer significant risk reduction for downstream communities. The first involves the construction of a 60m flood-detention dam but no lowering of the lake water level, resulting in a 43% reduction of risk, but requiring extensive infrastructure construction and expense. The second involves lowering the lake water level by 10m and constructing a 40m-high dam, resulting in a 58% reduction of risk. The third involves lowering the lake water level by 20m with no dam, resulting in a risk reduction of 67%. The Government of Nepal, in partnership with the United Nations Development Programme Nepal (UNDP/Nepal), is currently considering a fourth alternative. That is to lower the lake water level by 3m, which would result in approximately a 5% reduction of risk (UNDP, 2013). The latter, however, does not appear to offer significant risk reduction benefits to downstream communities compared with lowering the lake water level by 20m. Results suggest that either the lake water level must be lowered by significantly more than 3m (20m is recommended), or that a downstream flood-detention dam be included in the project. It has been suggested that siphons should be used to lower the Imja Lake water level. This would involve installing 13 pipes of 0.35m diameter, draining the water level by 3m, excavating it to the new water level and repeating the process until the level has been lowered by 20m.

In September 2013 and May 2014, field work involved the installation of instrumentation in the Imja glacier to monitor the temperature of the debris cover and to estimate the melting rate of the glacier (Rounce and McKinney, 2014). The data gathered will enable HiMAP to estimate the future evolution of Imja Lake, including the time it might take to reach a point where avalanches can enter the lake and become a threat (see Figure 6). It will also ensure that any glacial lake-lowering project design is based on quantified risk and vulnerability analyses and that it does, in fact, reduce the risk to downstream communities.

The rapid reconnaissance methods developed by the HiMAP demonstrate the need to establish solid working relationships with all key players at a project's outset. Perhaps the most important aspect of rapid reconnaissance for risk identification, however, is early and continuous communication of results with local community stakeholders because they are the groups with the greatest to gain from such a project.

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Local adaptation plans of action

Local communities in mountainous regions are particularly vulnerable to climate change – as global temperatures rise glaciers recede, new glacial lakes form and the weather becomes less predictable. Despite this, understandings of the human dimensions of climate change are still in their infancy in mountain regions where there is limited comprehension of climate change, its impacts, community vulnerabilities and adaptation opportunities.

In September 2010, the Government of Nepal initiated climate adaptation planning and implementation by endorsing the National Adaptation Programme of Action (NAPA). The Government's intention is to disburse at least 80% of the available budget earmarked for climate change directly to local implementation of identified adaptation actions. The NAPA also aims to ensure that national adaptation planning supports adaptation by local communities, particularly the climate-vulnerable poor.

In 2011, recognising the enormous variability within Nepal and within its various communities, the Government of Nepal developed the Local Adaptation Plan of Action (LAPA) process (see Figure 7). The LAPA is designed to more fully reflect the needs and aspirations of Nepal's diverse communities, as well as the wide range of impacts experienced from climate variability. There are a number of differences between the Government of Nepal (Figure 7) and the HiMAP adaptation planning approaches (see Figure 8). The first is that the HiMAP LAPA begins with an emphasis on *local development needs* in order to place the climate-centric LAPA into a broader development context. This involves a discussion of local assets, a 'sensitisation' (or introduction) to climate change basics and finally facilitated discussions of how these assets have been affected by climate change. Second, HiMAP spent a considerable amount of time in the integration of identified adaptation priorities into existing or forthcoming sources of development funding, such as those from Village Development Committees (VDCs), or the Sagarmatha NPBZ Committee. Efforts to include aspects of the LAPA into the revised Sagarmatha National Park Management Plan were also pursued because the existing Park plan contained no specific mention of, or projects related to, climate change. Third, the HiMAP Khumbu LAPA incorporated scientific data and knowledge to verify or challenge local experience and perceptions of climate change impacts and vulnerabilities. For example, results from the HiMAP glacial lake surveys and potential risks were routinely shared with participants and the Government of Nepal. This may have influenced the ranking of GLOFs as the number one hazard in terms of risks and impacts, despite a high level of local skepticism prior to the first years of HiMAP activity (2011–13). Finally, the HiMAP adaptation planning approach considered the entire Sagarmatha NPBZ – including the three VDCs (Chaurikharka, Namche and Khumjung – see Figure 1) inside the Park.[1] The decision was made because all three VDCs are located in high-mountain glaciated areas, have similar socio-economic and cultural characteristics, and are experiencing similar climate change related issues and climate change induced hazards. (Conversely, the Nepalese Government's approach was to use single VDCs.)

During community consultations, HiMAP employed 11 different participatory tools and techniques to gather and share information (see Figure 8). This integrated and comprehensive approach was felt to be more effective and efficient in the development of a climate change adaptation plan and tools for the Khumbu region.

The LAPA Framework consists of seven steps for integrating climate change resilience into local-to-national planning processes. Briefly, these are:

1. Climate change sensitisation
2. Climate vulnerability and adaptation assessment
3. Prioritisation of adaptation options
4. Developing a local adaptation plan for action
5. Integrating the local adaptation plan for action into planning processes
6. Implementing the local adaptation plan for action
7. Assessing progress of the local adaptation plan for action

Figure 7: *Précis of the Government of Nepal's, Local Adaptation Plan of Action (LAPA) Framework. Source: Government of Nepal, 2011.*

Key issues identified in the Khumbu LAPA

Six priority climate-induced hazards were identified and ranked in order of importance as follows: GLOFs, landslides, heavy snowfall, windstorms, forest fires and floods. Participants determined that, in the three Khumbu VDCs, a total of 1284 households would likely be affected by GLOFs and 927 by landslides. The impacts of heavy snowfall are more severe in Khumjung and Namche VDCs than in Chaurikharka VDC, but windstorm impacts are increasing in all three VDCs. Due to its lower elevation, and thus denser forests, Chaurikharka is more sensitive to forest fires than the other two VDCs. The occurrence of flash floods appears to be increasing every year, particularly in the Chaurikharka VDC.

Step	Tool	Technique (and outcomes)
1	Social map	Records settlements, villages, trails, bridges, services, forests, agriculture areas, development activities and other prominent features
2	Vulnerability map	Records villages, communities, forests and agriculture areas that have been or are prone to climate-induced hazards such as flooding, forest fires, GLOFs, windstorms, snowfall, drought and agricultural pests and diseases
3	Seasonal calendar	Analyses the local climate change experience in recent years. The experience is recorded using a monthly calendar and compares past experience with the present across climate variables
4	Historical timeline analysis	Analyses the occurrence and frequency of different climate-induced hazards during the past three decades and their impacts on communities, villages, agriculture and forest land, and infrastructure
5	Affected areas/ households analysis	Records the impacts of climate-induced hazards on villages, households and socio-economic groups based on social and vulnerability maps and historical timeline analyses
6	Climate-induced hazards ranking and impact analysis	Analyses hazards identified in the vulnerability map and the impacts of these on different sectors. A scale of 0–4 was used to score the local experience of intensity and the extent of the impacts on different sectors. This process records the ranking of various hazards in terms of their impacts on sectors that have been the most affected
7	Climate change impacts on different sectors	Analyses the present and potential impacts of climate change on different priority sectors as identified in the climate change ranking and impact analyses
8	Adaptation visioning	Records the impacts of the six most significant hazards as ranked and prioritised by climate change ranking and impact analysis tools
9	Adaptation prioritisation	Records different adaptation programmes and activities using four criteria (effectiveness, cost-effectiveness, feasibility and target group orientation) and prioritises them. A scale of 0–3 was used to score each criterion
10	Stakeholder analysis	Records and prioritises different organisations and institutions, governmental and non-governmental organisations and the private sector using a Venn diagram. This tool helps define the significance and importance of climate adaptation plans as well as the roles and responsibilities of each organisation
11	Implementation plan	Based on adaptation prioritisation, a detailed implementation plan of action is developed. The plan includes the top six identified hazards, the adaptation activities and their ranking in terms of importance and priority, possible funding sources and responsible organisations

Figure 8: *The HiMAP Khumbu local adaptation plan of action: participatory tools and techniques.*

Impact		Adaptation activities
1	Glacial lake outburst floods	a. Research and monitoring of glacial lakes b. Early warning systems c. Disaster management systems d. Insurance coverage and clothing for porters
2	Landslides	a. Nurseries and afforestation
3	Heavy snowfall	a. Weather monitoring and forecasting b. Snow and ice management training c. Green/plastic house demonstrations
4	Windstorms	a. Public awareness building
5	Forest Fires	a. Firefighting training and equipment b. Public awareness building
6	Floods	a. Public awareness building b. Afforestation

Figure 9: *Climate change impact and adaptation project priorities for the Khumbu region of Nepal.*

Adaptation project priorities

Four criteria were used to assess each adaptation option produced using the Adaptation Visioning Plan of Action tool (points 8 and 9, Figure 8). Figure 9 lists those climate change impact and adaptation project priorities with the highest scores for the Khumbu region.

A five-year implementation plan was then developed and prospective sources of funds for each identified. The Sagarmatha NPBZ Committee and VDCs were identified as the most promising organisations to integrate the high-priority LAPA initiatives into their existing and future developmental budgets. Meetings with each of these (and other organisations) began in January 2014, and the HiMAP LAPA steps 6 and 7 will continue throughout 2014 and 2015.

In terms of lessons learned, the Khumbu LAPA experience confirmed that taking a unit larger than a single VDC was an effective approach in terms of adaptation option prioritisation and resource mobilisation. In addition, this approach has the potential to become a model for sub-regional or district-level adaptation planning elsewhere in

Nepal. The actual integration of the LAPA into local, district and national planning has, however, proven to be challenging. This is largely due to a lack of available resources. Therefore, establishing formal relationships and memoranda of understanding with government agencies prior to the onset of community consultations is important so that roles, responsibilities and outcomes are clear from the beginning. Finally, while enthusiasm for the LAPA process among the VDCs was high, follow-through is (once again) matched by the availability of resources – which at present are scarce.

Conclusions

Since its official formation in March 2012, the HiMAP has successfully strengthened the scientific, social and institutional capacity for climate change adaptation and resilience in representative high-mountain glacial watersheds in Nepal. Each Local Adaptation Plan of Action is based on the principles of full community participation, climate-smart development, ecosystem-based adaptation approaches, risk mitigation and disaster management planning. Development outcomes have included a portfolio of high-mountain climate change adaptation mechanisms in line with regional priorities, each designed to address such priority vulnerabilities as reduced access to freshwater, increased landslides, increasing temperatures, GLOFs, emerging glacial lakes and geomorphic instability. The high-mountain glacial watershed international community of scientists and practitioners is pooling its knowledge. A new generation of 'climber-scientists' fluent in climate change and adaptation issues, field and laboratory methods, integration of traditional knowledge, active community engagement and climate-smart development, is emerging. Global awareness of the critical importance of high-mountain glacial watersheds has been increased among donors, international agencies and governments, such that they now actively support climate change adaptation and resilience-building in these regions.

Nevertheless, as promising as these results may be, it is clear that glacier-dominated areas of the world will continue to pose unique challenges to both upstream and downstream communities as they adapt to the impacts of global climate change – particularly the increasing threats of GLOFs. Glaciated mountains are among the least studied environments in the world from a physical, social and climate change perspective. As such, the processes of adaptation and mitigation appear more complex and challenging. Contemporary developments – such as the formation of thousands of new and, potentially, dangerous glacial lakes – are unprecedented in humankind's experience of change and adaptation. Given the critical importance of high-mountain glaciated landscapes to the millions of inhabitants of cities and communities that live in or rely upon them, interdisciplinary climate change research approaches and applied field programmes that actively combine the social, physical and engineering science dimensions will be required in order to achieve the best understanding of current and future climate-induced risks.

Note

1. Village Development Committees are made up of representatives from settlements within their locality.

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