

# Climate change induced glacier retreat and risk management Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia

---

## Authors

Dirk Hoffmann

Instituto Boliviano de la Montaña – BMI

Casilla 3-12417, La Paz, Bolivia

Email: dirk.hoffmann@berlin.de

Daniel Weggenmann

Heidelberg University

Germany

Email: D-Weggenmann@gmx.de

## Contact address

Dirk Hoffmann

Instituto Boliviano de la Montaña – BMI

Casilla 3-12417, La Paz, Bolivia

Email: dirk.hoffmann@berlin.de

## Short introduction

Accelerated melting of glaciers due to global warming is a world wide phenomenon and tropical glaciers are especially vulnerable. Glacier retreat also increases the risk of climate hazards, such as glacier lake overflows, known as GLOFs.

In this paper we present documentation of glacier retreat and the forming of glacial lakes in the *Cordillera* of Apolobamba in the Bolivian Andes over the last 35 years.

In addition, the potential risk of outburst floods is analyzed, as well as possible management options for the local population and Apolobamba national park administration are being discussed.

## Biosketch

Dirk Hoffmann holds a first degree M.A. in Latin American Studies of Free University Berlin and is MSc Environmental Protection from Humboldt University Berlin.

From 2009-11 he was working with the Ecological Institute (IE) of Bolivian state university Universidad Mayor de San Andrés (UMSA), La Paz, as coordinator of the Climate Change Research Program.

Climate change induced glacier retreat and risk management Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia

At present he is director of the Bolivian Mountain Institute – BMI, a non-profit foundation with seat in La Paz.

The subject of his ongoing PhD is the influence of protected areas on landscape transformation in high mountain regions under conditions of climate change.

Daniel Weggenmann received his Diploma from Heidelberg University in 2011. In his thesis he studied the development of the glacial lakes in the Apolobamba Mountain Range in the context of climate change.

## Key words

Key words: climate change, glaciers, GLOF risk management, Apolobamba, Bolivia

## Abstract

Due to global warming, tropical glaciers in the Bolivia Andes have lost about half of their volume and surface area since 1975.

Throughout the Apolobamba mountain range, the retreat of glaciers has resulted in the formation of small and medium sized lakes on the glacier terminus. Many of the glacial lakes are contained only by loose moraine debris, thus they can pose a significant threat to human settlements and infrastructure downstream.

Considering the fact that the *Cordillera de Apolobamba* holds the largest continuous glaciated area in Bolivia, which measured 220 km<sup>2</sup> in the 1980s, there is a legitimate concern regarding the dangers that might affect this mountain region. Yet, there is no documentation available on glacial lakes in the Apolobamba mountain range; indeed there is little awareness of the related risks.

Only recently has glacial retreat, as well as climate change impacts on the whole, been given some importance in the planning and management of the Apolobamba National Protected Area for Integrated Management, thereby opening a discussion on natural hazard threats and the development of adaptation strategies with the objective of minimizing risks for human populations and local infrastructure.

This paper presents documentation of glacier retreat and the forming of glacial lakes in the *Cordillera* of Apolobamba over the last 35 years. In addition, the risk potential of glacial lake outburst floods and the risk awareness of the local population will be analyzed in relation to park management options and ideas lined out for more detailed studies of glacial lake outburst floods in Bolivia.

## Climate Change, glaciers and glacial lakes

### Global warming and climate change scenarios

Climate change is a reality today and its consequences can already be seen quite clearly in the Bolivian Andes (Oxfam, 2009, Hoffmann, 2010c). Temperature, precipitation and humidity have changed significantly over the last half century (Vuille et al., 2008). Studies now show a temperature increase of around 0.32 to 0.34° C per decade – compared to around 0.10° C for the decades after 1939 (Oxfam, 2009).

Due to complex topography of the Andes, climate change projections are difficult to make, and validated regional climate models only exist for a few mountain areas such as the

European Alps (Neu, 2009, PNUD-Bolivia, 2011). Global scenarios, as those developed by the Intergovernmental Panel on Climate Change – IPCC, are still to large in scale, as to give meaningful projections for individual mountain locations.<sup>1</sup>

Evidence from other mountain regions of the world (Rocky Mountains, Swiss Alps) as well as scenarios for the Andes shows that temperature increase is higher at higher elevations (Bradley et al., 2006, IPCC, 2007). This leads Vuille et al. (2008) to state that warming in the tropical Andes is likely to be of similar magnitude as in the Arctic – which is several degrees above global average.

As to precipitation changes, they are even more difficult to predict for mountainous areas due to the heterogeneity of the landscape (Hoffmann et al., 2011). In addition, the Andes region is heavily dependent on changes in the El Niño (ENSO) patterns, a natural climate phenomenon, which are still poorly understood (Neu, 2009, IPCC, 2007).

### Glacial retreat

Due to global warming and climate change, retreat of tropical glaciers located in the Central Andes has been observed over the past two decades. Some scientists believe that the melting of glaciers and changes in mountain ecosystems may provide an early glimpse of what could come to pass also in other environments, and that mountains thus act as early warning systems (Neu, 2009).

In Bolivia, an unknown number of the smaller and lower altitude glaciers have already disappeared. According to current climate change forecasts, a temperature increase between 5-6° C is expected to occur at altitudes higher than 5.000m during the 21<sup>st</sup> century (IPCC, 2007). A temperature increase of this magnitude will likely cause disappearance of the majority of tropical glaciers in Bolivia's *Cordillera Oriental* by the middle of this century (Hoffmann, 2010b, Painter, 2007). This will have grave consequences for local hazard potential and water cycles (Haeberli and Zemp, 2009).

### Forming of glacial lakes

Glacial lakes can be found in all mountain ranges in the world with presence of glaciers. After the so-called the Little Ice Age (1550-1850), when glaciers begun to shrink, moraines were formed at the glacier tongue (Mool et al., 2001). In the context of global warming induced glacier shrinkage many glacial lakes have been formed between the retreating glacier und the former end-moraine, thus leading to widespread GLOF hazards, sustain (Kaltenborn et al., 2010). The rapid accumulation of water can lead to a moraine breach. The huge amount of discharge contains water and debris and poses the most dangerous glacier hazard to downstream people and infrastructure (Richardson and Reynolds, 2000). These disastrous flood waves are generally known as Glacial Lake Outburst Flood (GLOF).

In the near past Glacial Lake Outburst Floods have destroyed infrastructure mostly in developing countries and killed thousands of people (Richardson and Reynolds, 2000, Ives et al., 2010). In Peru glacial lakes are investigated and monitored since an outburst flood

---

<sup>1</sup> The IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP); for further information on its role see EAMER, J., LAMBRECHTS, C., PRESTRUD, P. & YOUNG, O. 2007. *Policy and Perspective*, United Nations Environment Programme.

Climate change induced glacier retreat and risk management Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia

destroyed the city of Huaráz in 1941 and killed 4,500 people (Lliboutry et al., 1977). In Central and South Asia a huge amount of glacial lakes are identified after several catastrophic discharges (Richardson and Reynolds, 2000, Yamada, 1998, Mool et al., 2001). Clague and Evans (2000) studied glacier flood waves in the Rocky Mountains, in particular in Western Canada. The risk of glacial lake outburst floods in the European Alps has a different dimension, because the lakes are smaller and the infrastructure and settlements are generally much closer to the hazard sources (Huggel et al., 2002). Here even small lakes can cause serious damage (Huggel et al., 2002). Haeberli (1983) compiled the data of disastrous floods in the Alps and mentioned that inventories of glacial lakes and potential dangerous glacial lakes rarely exist.

## **Glacial retreat and the formation of glacial lakes in the *Cordillera Apolobamba***

### **The Apolobamba mountain range**

The *Cordillera Apolobamba* is the Northernmost part of the Eastern branch of the Andean *Cordillera* in Bolivia; reaching into Peru. It lies about 250 km northwest of La Paz and north of Lake Titicaca. It forms part of the *Cordillera Real*, which in turn is part of the *Cordillera Oriental*, the Eastern Andean mountain chain. It stretches along for some 75 km, regularly reaching heights of more than 5.000m, and with various peaks higher than 5,500 m (Montes de Oca, 2005, SERNAP, 2006a).

The Apolobamba mountain range is one of the least explored and less accessible mountain ranges in the Andes, with various peaks higher than 5,500 m. The high mountain area is characterized by vulnerable ecosystems, depending heavily on glaciers, which are subject to intense melting due to global warming.

Climate change induced glacier retreat and risk management Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia

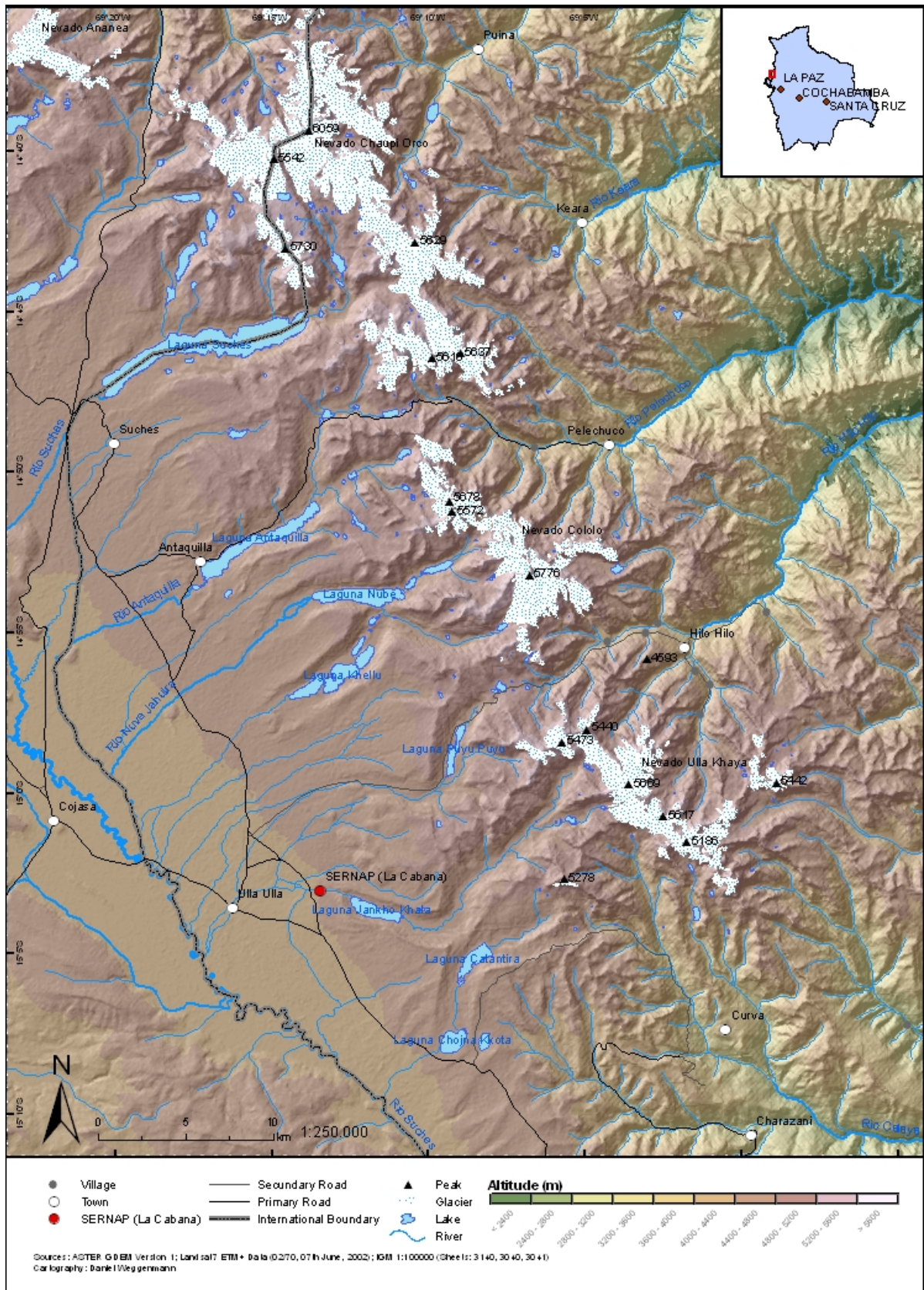


Figure 1: Map of Cordillera Apolobamba, glaciated area and glacial lakes

Historically, the whole region used to be Caupolicán province, which is today made up of the provinces of Franz Tamayo and Abel Iturralde, which in turn comprise the *municipios* of Pelechuco, Curva and Charazani. Apolobamba is not only biologically a very diverse and species rich area (Tarquino and Flores, 2011), but also in terms of cultural diversity: The local Kallawaya population has been declared Intangible Cultural Heritage of Humanity by the UNESCO in 2003.

Over the centuries, this mountain range, which now forms part of the Apolobamba Protected Area (formerly: Ulla Ulla), has acted as a barrier as well as an intersection between the *altiplano* highland and the Amazon lowlands. At present, there are more than 16,000 inhabitants in the area above 3,000 metres, the majority of whom make a living off the land as small scale farmers and herders. Only a fraction of the population is traditionally ascribed as being Kallawaya, a term referring to the itinerant Andean “healers” or shamans, using medicinal plants from the region.

Yet, on the basis of the country’s new constitution (2009), attempts are under way now to constitute this region as an autonomous indigenous Kallawaya territory. It is unclear what would happen with the numerous non-kallawaya population of the area in such a context. Another still unresolved question is what role would the newly instituted “traditional” local decision-making bodies play versus the existing municipalities.

### **Glacier recession in the Bolivian Andes**

Modest glacier recession in the Bolivian Andes - as elsewhere in the world - started in the last decades of the 19<sup>th</sup> century, after the end of the Little Ice Age (LIA) (Vuille et al., 2008).

The accelerated melting of glaciers however commenced around 1980. At that time, glacier area in Bolivia’s mountain ranges was calculated to be 566 km<sup>2</sup> by German geographer Ekkehard Jordan (1991). According to the World Glacier Monitoring Service, Bolivia holds 534 km<sup>2</sup> of glaciated area (WGMS, 2008), using data from Kaser & Osmaston, 2002).

Thus far research on glacial retreat has focussed largely on the Bolivian *Cordillera Real*, with a recent study of 376 glaciers (based on exact photogrammetric measurements of 21 glaciers) coming to the conclusion that the glacier volume loss between 1963 and 2006 mounted to 43%, and the surface area loss for the period 1975-2006 was 48% (Soruco et al., 2009).

Even though there is almost no documentation available on glacial retreat in the Apolobamba mountain range, which accounts for about 7.5% of the world’s tropical glaciers (Jordan, 1991), the results for the *Cordillera Real* from Soruco et al. (2009) and his team suggest that the *Cordillera Apolobamba* must have experienced a similar decline over the past 35 years. This data is corroborated by Tarquino and Flores (2011).

It is thus safe to assume that tropical glaciers in the Bolivia Andes have melted away noticeably since 1975, resulting in a reduction in surface area and volume of around 50 per cent. And considering the present rate of global warming, it is also safe to assume that the majority of the smaller and low-lying glaciers will disappear within a few decades (Hoffmann, 2008, Vuille et al., 2008).

### **Glacial lakes in the *Cordillera* of Apolobamba**

Considering the fact that the *Cordillera de Apolobamba* holds the largest continuous glaciated area in Bolivia which measured 220 km<sup>2</sup> or a good third of Bolivia’s glacier area in the 1980s; data from Jordan (1991), under conditions of climate change it is an area destined for the forming of glacier lakes.

Climate change induced glacier retreat and risk management Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia

The Bolivian part is subdivided into three glacier regions (from North to South): Chaupi Orco, Cololo and Ulla Khaya, separated by the *Abra de Pelechuco* (Pelechuco Pass) and the *Abra de Sorapata* (Sorapata Pass).

The Chaupi Orco region holds 129 km<sup>2</sup> of glacier area and is home to 346 glaciers; the Cololo region holds 43 km<sup>2</sup> and 135 glaciers, and the Ulla Khaya region harbors 47 km<sup>2</sup> and 171 individual glaciers (Jordan, 1991).

As to the “glacial lakes”, however, a note of caution: in various, especially older texts (Martin, 1965, Seltzer et al., 1995), the reference to “glacial lakes” is to those lakes that have formed 18 – 25.000 years ago at the end of the Last Glacial Maximum (LGM), which means they have existed all through the Holocene.

They are the remains of the Late Pleistocene glaciation of the Apolobamba mountain range took place in three marked advances, leaving behind a number of large glacier lakes on the shallow Western side towards the Ulla Ulla high plain, the largest of them being the lakes Suches, Cololo, Nubi, Khellu and Jankho Khala (Rafiqpoor, 1994, Lauer and Rafiqpoor, 1986).

We, however, are only concerned with those glacial lakes of recent formation, which date from the last 30 years, are higher up in the mountains and much smaller than those mentioned before.



**Figure 2: Moraine dammed Laguna Isquillani in Apolobamba´s Ulla Khaya region.**

(Source: Dirk Hoffmann, May 2011)

Data on the lake (2008) – length: 574m; area: 0.079 km<sup>2</sup>; volume: 0.937 km<sup>3</sup>; change in area between 1986-2008: 8,22% (Weggenmann, 2011).

Throughout the Apolobamba mountain range, the retreat of glaciers has resulted in the formation of small and medium sized lakes on the glacier terminus. Many of the glacial lakes are contained only by loose moraine debris, thus they can pose a significant threat to human settlements and infrastructure downstream (see Fig. 2). Yet, there is no documentation available on glacial lakes in the Apolobamba mountain range.

Over the past 25 years, from 1986 to 2008, the number of contemporary glacier lakes has gone from 174 to 216 for the whole *Cordillera* Apolobamba, which is an increase of more than 20% (Weggenmann, 2011). The total lake area has gone up during the same time span from 47,882 km<sup>2</sup> auf 50,062 km<sup>2</sup>. The average lake size is about 0,231 km<sup>2</sup>. The average growth rate in area from 1986 to 2008 is about 4.5 % and the percentual change in numbers is about 24 % (Weggenmann, 2011).

## **GLOF risks in Apolobamba**

### **GLOF risks**

Haeberli and Zemp (2009). point out that these new lakes that form in local depressions of glacier beds that are now becoming exposed constitute a growing hazard for flood waves and debris flows caused by moraine breaching or by rock avalanches from de-glaciated slopes, or those containing degrading permafrost (Haeberli and Zemp, 2009). Similarly, Neu sustains that the “melting of glaciers and permafrost will trigger the release of loose rock and soil and exacerbate the danger of rockfall, debris flows, and mud flows. A specific risk is the build-up of glacial lakes and the threat of lake outbursts, which could result in destruction of property and death” (Neu, 2009).

Glacial Lake Outburst Floods (GLOFs) represent the most dangerous and far reaching glacial hazard in high mountain areas. The serious risks relate to loss of human life and destruction of costly infrastructure such as hydropower plants, roads and agricultural land (Huggel et al., 2004, Richardson and Reynolds, 2000). This risk is likely to increase in the future, as continued glacier recession will lead to lake formation on the larger glaciers at higher altitudes (Kaltenborn et al., 2010).

In contrast, the most recent and most comprehensive compilation on the state of knowledge about climate change, water and food security in Bolivia does not mention the possibility of GLOFs in mountain regions, even though it has a whole chapter dedicated to climate risks and risk management (PNUD-Bolivia, 2011).

Huggel et al. (2004) further alerts that glacier floods are triggered by the outburst of water reservoirs in, on, underneath and at the margin of glaciers, while outbursts from moraine-dammed lakes can be triggered by overtopping, piping, slippage on steep slopes or a combination thereof (Huggel et al., 2004). The risk due to a moraine breach outburst flood is very high in almost all glaciated mountain ranges in the world (Haeberli, 1983, Clague and Evans, 1994, Yamada, 1998).

Among the triggers of glacial lake outburst floods we also find earthquakes, a subject that has been given fairly little attention in the last decades (despite the Huaraz incident in 1970), and only recently has been mentioned, in relation with Himalayan glaciers (Singh Khadka, 2011, Ives et al., 2010). There are however no systematic studies, neither in the Himalayas nor in the Bolivian Andes. Because of the remoteness of many glacial lakes, there is often a lack of even basic data of potential dangerous areas and the local communities under risk.

### **The Keara incident, November 2009**

The possibility of a GLOF in the Bolivian high Andes is no longer only a theoretical possibility: On November 3, 2009, at about 11:00 a.m. a glacial lake above the small village of Keara, in Apolobamba's Chaupi Orco region, emptied its contents within a few minutes and sent a wave of water downstream, flooding cultivated fields, destroying several kilometres of a local dirt road, washing away pedestrian bridges and killing a number of farm animals.



Climate change induced glacier retreat and risk management Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia

The small community of Keara on the Eastern Andean slopes at an altitude of around 3,800 meters, which belongs to the *municipio* of Pelechuco, was left without road communication for several months.



**Figure 3: Satellite image of the ice dammed glacial lake above Keara**

(Source: Google Earth, 4th August 2005)

Satellite images obtained from google.earth clearly show the glacier that holds up the lake. There was no technical enquiry and it has not been established, what exactly had happened. Still, this is up to now the only documented case of a glacier lake outburst flood, thanks to the field technician Martín Apaza, who, accompanied by locals, went up to the lake the day after the outbreak, took photographs and filed a first-hand report (Apaza Ticona, 2009)



**Figure 4: The glacial lake after the outbreak**

(Source: Martín Apaza Ticona, 4th November 2009)



**Figure 5: Breach in the moraine dam below the glacial lake**

## Preliminary risk assessment and classification of glacial lakes

Throughout the Cordillera range, the retreat of glaciers has resulted in the formation of small and medium sized lakes. Many of the lakes are geologically volatile, contained only by loose moraine debris, and pose a significant natural hazard threat to human settlements and infrastructure located below. Considering the prevalent occurrence of similar natural disasters (i.e. GLOF – Glacial Lake Outburst Floods) in other regions of the Andes and Himalayas, there is legitimate concern of the dangers that may affect many mountain regions of Bolivia (Hoffmann, 2010b).

The majority of glacial lakes in the Andes have not been identified or studied properly. This, in large part, is due to the remoteness of the high mountain regions (Huggel et al., 2002). In Bolivia up to now none of the more than 200 glacial lakes have been studied. Also, common maps in Bolivia either have been elaborated or are using data decades old, where glacial lakes formed in context of climate change are not included. Many of the recent glacier lakes started forming during the last 30 to 40 years, after accelerated glacier recession due to climate change set in.

In view of this reality, the BMI – Bolivian Mountain Institute has proposed a detailed investigation of all glacial lakes in the *Cordillera Oriental* and to evaluate categories of risks for each (Hoffmann, 2010b). Due to lack of funding this has not been possible to realize until now. However, thanks to the interest and initiative of German geologist Daniel Weggenmann of Heidelberg University a beginning has been made: As part of this graduate thesis, Weggenmann has produced a glacial lake inventory for the whole *Cordillera Apolobamba*, the main glaciated mountain range in Bolivia (Weggenmann, 2011)

It is thus that we can consider the detection of glacial lakes as a necessary first step towards the process of investigation into the possible risks associated. This step corresponds with “Level 1” of the methodological approach suggested by Christian Huggel et al. (2002): “The first level comprises the basic detection of glacier lakes over large areas” (Huggel et al., 2002). To achieve an overview of the existing lakes, the NDWI (normalized difference water index) performed by Huggel et al. (2002) was used. Level 2 and Level 3 involves more detailed investigation of lakes detected in Level 1. Further on, we used not only topographical maps and satellite images, hydrological maps as well as the compilation of glacier maps elaborated by German geographer Ekkehard Jordan (1991).

In a second phase, this information will have to be complemented with data about infrastructure, human settlements and general terrain characteristics to allow for an assessment of potential damage. Topography is an especially important factor when assessing risk of glacier lake outburst floods. There is a marked difference between the shallow slopes on the Western side and the abrupt and narrow valleys on the Eastern side of the Apolobamba mountain range.

At present, such a risk assessment is being undertaken, which will provide us with a general vision and complete overview of the existence and dynamics in the *Cordillera Apolobamba*, Bolivia’s main glacierized region. It will also come up with a classification and a listing of those lakes considered most dangerous (Weggenmann, 2011). These should consequently be monitored and studied in more detail, including aspects of human vulnerability.

Municipal and other planners will have to integrate this information into spatial and infrastructure planning, in order to put the results of the present glacier lake risk assessment into practice and thus help communities and the protected area in the region prepare for these potential risks.

## Social and political responses

### **The “National Area for Integrated Nature Management – Apolobamba, ANMIN-A”**

As social and political setting we will consider, on the one hand, the Apolobamba National Protected Area for Integrated Management (ANMIN), and on the other, the three municipalities involved with the glacierized upper part, namely Pelechuco, Curva and Charazani.

The area was first declared by in 1972 as National Reserve Ulla Ulla for the protection of the vicuna, with a size of approximately 240,000 ha (Supreme Decree D.S. 10070). In 1977 it was recognized as a UNESCO Biosphere Reserve. More than a decade later, in 2000, and again by Supreme Decree (D.S. 25652), the area was expanded to 483,743 ha and received a new name and category: National Area for Integrated Natural Management – Apolobamba, or “ANMIN-A” (Ribera and Libermann, 2006, SERNAP, 2006a, SERNAP, 2006b). Its altitudinal range goes up from around 800 to more than 6,000 metres in the Chaupi Orco region. ANMIN-Apolobamba is by far the national protected area with the largest glacier area, holding about 150 km<sup>2</sup> or one third of all Bolivia’s glaciers.

ANMIN-Apolobamba is situated in the West of the department of La Paz, and administratively speaking is part of the provinces Bautista Saavedra, Franz Tamayo and Larecaja, as well as of the following *municipios*: Charazani, Curva, Pelechuco and Guanay. It sustains a population of 18,500.

The area also holds a number of archeological sites, pre-Columbian routes and is home to the Kallawayaya culture, declared “masterpiece of oral and intangible heritage of humanity” (Layme et al., 2007).

The park’s management plan dates from 2006 and is the central planning document (SERNAP, 2006a). In its “diagnosis” there is a brief mention of climate change and glacier retreat, but on the whole this topic is not developed further; glacial lakes are not even mentioned.

Only recently has glacial retreat, as well as climate change impacts on the whole, been given some importance in the planning and management of the Apolobamba National Protected Area for Integrated Management, thereby opening a discussion on natural hazard threats and the development of adaptation strategies with the objective of minimizing risks for human populations and local infrastructure.

The management plan is presently being adjusted to the new realities existing after the voting of a new Constitution in 2009, which presents park managers with a unique opportunity to put adaptation to climate change in a prominent place of the park’s future agenda. One of the issues that should urgently be addressed is the existence and ongoing formation of glacial lakes at high altitudes. Integral risk potential analysis should be carried out, involving local communities who would be the ultimate beneficiaries of the initiation of glacial lake management activities. The park could thus play a leading role in disaster risk mitigation and adaptation of local communities to the impacts of climate change.

## Risk awareness of local actors

Melting glaciers are widely recognized as being the most visible sign of climate change, due to their often very fast response time and the clear visibility of their reaction to the public (Vuille et al., 2008, Hoffmann, 2010a). This, however, does not mean that glacial lakes have also acquired a more prominent place in the eyes of the people.

Until now, in all publications about the impacts of climate change on protected areas in Bolivia, the focus is exclusively on biodiversity and water availability, but there is no consideration of GLOF risks (Arnold Torrez and Barroso Pauletti, 2008, Hoffmann, 2010c).

It is in this context that the theme of the International Mountain Day celebrated by the United Nations in 2009, “risk management of catastrophes in mountain regions” explicitly mentioned GLOFs as a risk for mountain dwellers (FAO, 2009) - a sign of the growing attention that they are receiving on the international level.

Talking to the local population and park staff of Apolobamba immediately shows that there is indeed very little awareness of the risks related to glacial lagoons. The same holds true for the political and administrative personnel of the three small municipalities. Part of the explanation is probably given by Huggel et al. (2004), when he emphasizes the fact that glacier retreat and permafrost degradation might lead to conditions never before experienced in historical times (Huggel et al., 2004). Risks related to glacial lakes are completely new, local societies do not have any references to understand and assess them, let alone react to them, leaving them virtually unprepared.

Two workshops on “local perceptions of climate change” that were held as part of the GLORIA project on long term observation of high mountain biodiversity in the face of climate change in the upper parts of Apolobamba (Communities of Puyo Puyo and Cañuma) close to the glaciated areas of the Ulla Khaya region, did not reveal any sense of danger in relation to these newly formed glacial lakes. The workshop report reads as follows:

*“The Cordillera Apolobamba presents glaciers along its whole extension, that are being converted to water. The existence of numerous lakes in the high parts, as well as several streams are a big social and environmental potential. The high altitude lakes have developed an intensive fish production (commercial trout breeding), and also of native species. Studies have demonstrated the potential those lagoons hold, besides being a landscape attraction for tourism.”* (Canqui, 2008, own translation)

In each of the workshops around 50 villagers participated, interacting with a group of researchers from La Paz´ UMSA state university in focussed discussion groups and plenary sessions. Considering the number of communities in the Apolobamba region and the cultural diversity of the different population groups, the area of local perceptions of climate change clearly needs further research, especially from the various social science disciplines.

## Establishment of a (glacial lake) monitoring system

In relation to the potential risk of glacier lake outburst floods, various authors call for risk management, hazard mapping as well as risk monitoring and installation or improvement of early warning systems (Marty, 2009, FAO, 2009). Glacial lakes, however, are still not seen as being a risk to populations, neither by authorities nor the local people themselves. The total surprise of the community of Keara towards the GLOF event of November 2009 made clear that there exists no traditional practice with these type of hazards. The incident, however, triggered a discussion within the community and it will have to be seen, where this process leads. Possibly to the relocation of part of the village in order to strengthen the community´s

resilience to glacial lake outburst floods in the wake of continued global warming? Here we have a challenging research topic for anthropologists into the originating conditions for community based adaptation, or even a first step towards a community based management of newly formed glacial lakes.

In 2010 the park management of Apolobamba National Area for Integrated Nature Management decided to establish a monitoring system, considered crucial to monitor biodiversity and the use of natural resources by locals within the protected area (Tarquino and Flores, 2011).

Following the national parks administration's tradition of participatory planning, the monitoring system has been set up with the participation of the park rangers, together with a small team of technical assistance. The monitoring system is based on the strategic areas defined for the planning of the whole System of Protected Areas, one of those areas being the "preservation of the natural and cultural heritage" (Tarquino and Flores, 2011). The following elements have been defined as objects of the monitoring: water bodies, glaciers, traditional tubers, fauna, Andean peat bogs (*bofedales*), climate, conflicts, mining, and knowledge of traditional medicinal plants, rituals and ruins.

Efforts by scientists have been successful to convince park guards and representatives of local populations, that glacial lakes indeed might pose a risk and thus should be monitored. Once the complete analysis of glacial lakes is available, it is hoped that a small number of lakes can be regularly visited. Monitoring is being realized by park guards themselves in intervals of about two months. It is also hoped that these monitoring activities will lead to the park guards informing the local communities about possible risks associated with these newly formed glacial lakes.

Additional efforts are currently under way to integrate photographic glacier and glacial lake monitoring into the monitoring system of ANMIN Apolobamba as part of its management scheme. The photographs will also be used for public awareness campaigns, in recognition of the fact that visual evidence is often the most convincing way of disseminating knowledge to a non-scientific audience (Byers, 2007).

## Conclusions

Glacial retreat, as climate change impacts on the whole, have not yet been given the importance it requires in the planning and management of ANMIN Apolobamba. There is however a growing and legitimate concern regarding the dangers that might affect this mountain region, including the possibilities of glacial lake outburst floods (GLOF).

The classification and listing of the Apolobamba glacial lakes according to their risk potential, which is being prepared by Weggenmann (2011), will be a valuable input for the local monitoring of the most dangerous of those lakes.

In the second phase of research, still to be undertaken, empirical studies of the landscape will be shared with municipalities and local communities, thereby opening the discussion on natural hazard threats and the development of adaptation strategies with the objective of minimizing risks for human populations and local infrastructure (Hoffmann, 2010b).

A direct policy implication is the critical need to promote multiple stakeholder platforms in land-use planning (López Sotomayor, 2008), fostering dialogue mechanisms and improve mutual knowledge of stakeholders as part of the participatory process. Here various actors are being called upon. Will local communities be willing and able to pressure for such a process to be organized? Will the municipal government of Pelechuco understand the new challenges

posed by retreating glaciers and act upon them accordingly? And, maybe most importantly, will the park's new director push for the continuation of the monitoring system and give priority to its implementation? Very much depends on each of these actors as well as their mutual interactions, if the attempts of channelling these emerging challenges into the existing local institutionality in order to provoke concrete action.

The ANMIN Apolobamba monitoring system is not only an innovative approach towards participatory monitoring, in that park guards themselves have a key role in the planning and implementation. It is also an example of inter-institutional alliances, bringing together state actors (SERNAP national parks administration and municipalities), academic and research institutions (Ecological Institute of UMSA university and Bolivian Mountain Institute – BMI) with local actors (*comunidades*, park guards and Apolobamba management committee).

Last, but not least, it is a concrete and practical example of local adaptation to climate change.

## Acknowledgements

We would like to thank in the first place the park guards and the former director of Apolobamba National Area for Integrated Natural Management and Rodrigo Tarquino for their help and assistance, as well as three anonymous reviewers for valuable comments.

## References

- Apaza Ticona, M. (2009), "Reporte preliminar del desastre natural en la comunidad de Keara", 6 noviembre 2009, La Paz: field report (unpublished)
- Arnold Torrez, I. and Barroso Pauletti, P. (2008), "Áreas protegidas de Bolivia", Situación y Perspectivas de gestión", Tarija
- Bradley, R., Vuille, M., Díaz, H. and Vergara, W. (2006), "Threats to water supplies in the tropical andes", *Science*, 312, 1755-1756
- Byers, A. C. (2007), "An assessment of contemporary glacier fluctuations in Nepal's Khumbu Himal using repeat photography", *Himalayan Journal of Sciences*, 4, 21-26
- Canqui, F. (2008), "Segundo informe de los talleres de percepciones del cambio climático", comunidades Canuhuma y Ayllu Puyo Puyo, La Paz: technical report (unpublished)
- Clague, J. and Evans, S. (1994), "Formation and failure of natural dams in the Canadian Cordillera", *Bulletin - Geological Survey of Canada*, 464
- Clague, J. and Evans, S. (2000), "A review of catastrophic drainage of moraine-dammed lakes in British Columbia", *Quaternary Science Reviews*, 19, 1763-1783
- Eamer, J., Lambrechts, C., Prestrud, P. and Young, O. (2007), "Policy and Perspective, United Nations Environment Programme", FAO 2009, *Disaster Risk Management in Mountains*
- Haeberli, W. (1983), "Frequency and characteristics of glacier floods in the Swiss Alps", *Annals of Glaciology*, 4, 85-90
- Haeberli, W. and Zemp, M. (2009), "Mountain Glaciers: On Thin Ice", In: Kohler, T. and Maselli, D. (eds.), "Mountains and Climate Change: From Understanding to Action", Bern: Geographica Bernensia

Climate change induced glacier retreat and risk management Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia

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 montaña: Inventario de las lagunas glaciares de la Cordillera Real de Bolivia", In: Beck, S. G., Paniagua, N., López, R. P. and Nagashiro, N. (eds.), "Biodiversidad y Ecología en Bolivia: Simposio de los 30 años del Instituto de Ecología", La Paz: Instituto de Ecología, Universidad Mayor San Andrés

Hoffmann, D. (2010c), "El cambio climático y las áreas protegidas de Bolivia", In: Beck, S. G., Paniagua, N., López, R. P. and Nagashiro, N. (eds.), "Biodiversidad y Ecología en Bolivia", Simposio de los 30 años del Instituto de Ecología, La Paz: Instituto de Ecología - Universidad Mayor San Andrés

Hoffmann, D., Oetting, I., Arnillas, C. A. and Ulloa, R. (2011), "Climate Change and Protected Areas in the Tropical Andes", In: Herzog, S. K., Martínez, R., Joergensen, P. M. and Tiessen, H. (eds.), "Climate Change and Biodiversity in the Tropical Andes", Inter-American Institute for Global Change Research (IAI), Scientific Committee on Problems of the Environment (SCOPE)

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

Huggel, C., Haeberli, W., Kaab, A., Bieri, D. and Richardson, S. (2004), "An assessment procedure for glacial hazards in the Swiss Alps", *Canadian Geotechnical Journal*, 41, 1068-1083

Huggel, C., Kaab, A., Haeberli, W., Teyssere, P. and 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

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, Cambridge University Press

Ives, J. D., Shrestha, R. B., Mool, P. and International Centre for Integrated Mountain Development (2010), "Formation of glacial lakes in the Hindu Kush-Himalayas and GLOF risk assessment", Kathmandu, International Centre for Integrated Mountain Development

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*, Stuttgart, Steiner

Kaltenborn, B. P., Nellemann, C. and Vistnes, I. I. (2010), "High mountain glaciers and climate change: Challenges to human livelihoods and adaptacion"

Lauer, W. and Rafiqpoor, M. (1986), "Die jungpleistozäne Vergletscherung im Vorland der Apolobamba Kordillere (Bolivien)", *Erdkunde*, 40, 125-147

Climate change induced glacier retreat and risk management Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia

Layme, L., Callancho, R. B. and Sarmiento, Q. (2007), "Conoce el Área Natural de Manejo Integrado Nacional Apolobamba", La Paz

Lliboutry, L., Morales Arnao, B., Pautre, A. and Schneider, B. (1977) "Glaciological problems set by the control of dangerous lakes in Cordillera Blanca, Peru", I. Historical failures of morainic dams, their causes and prevention, *Journal of Glaciology*, 18, 239-254

López Sotomayor, G. (2008), "Responding to the Collapse of Mountain Ecosystem Health and Natural Resource Management Institutions in Peru", *IHDP Update*, October 2008, 41-45

Martin, S. W. (1965), *Glacial Lakes in the Bolivian Andes*, *Geographical Journal*, 131, 519-526

Marty, C. (2009), "Natural Hazards and Risk in Mountains: The Potential Impacts of Climate Change", In: Kohler, T. and Maselli, D. (eds.), "Mountains and Climate Change: From Understanding to Action", Bern: Geographica Bernensia

Montes de Oca, I. (2005), "Enciclopedia Geográfica de Bolivia", La Paz

Mool, P., Bajracharya, S. R., Joshi, S. P. and International Centre for Integrated Mountain Development, Mountain Environment and Natural Resources Information System (2001), "Inventory of glaciers, glacial lakes, and glacial lake outburst floods: monitoring and early warning systems in the Hindu Kush-Himalayan Region", Nepal, Kathmandu, Nepal, International Centre for Integrated Mountain Development, Mountain Environment and Natural Resources' Information Systems

Neu, U. (2009), "Climate Change in Mountains", In: Kohler, T. and Maselli, D. (eds.), "Mountains and Climate Change: From Understanding to Action", Bern: Geographica Bernensia

OXFAM (2009), "Bolivia: Climate change", poverty and adaptation, La Paz

Painter, J. (2007), "Deglaciation in the Andean Region", *Human Development Report 2007/08*

PNUD-Bolivia (2011), "Tras las huellas del cambio climático en Bolivia", *Adaptación en Agua y Seguridad Alimentaria*, La Paz

Rafiqpoor, M. (1994), *Geomorphological mapping in the Apolobamba Cordillera, Bolivia: application of the GMK 100 legends concept in high mountains of the marginal tropics*, *Erdkunde*, 48, 241-258

Ribera, M. O. and Libermann, M. (2006), "El uso de la Tierra y los Recursos de la Biodiversidad en las Áreas Protegidas de Bolivia", *Un análisis crítico con propuestas para su conservación y manejo sostenible*, La Paz: Servicio Nacional de Áreas Protegidas (SERNAP) Proyecto GEF-II Banco Mundial

Richardson, S. D. and Reynolds, J. M. (2000), "An overview of glacial hazards in the Himalayas", *Quaternary International*, 65-6, 31-47

Seltzer, G., Rodbell, D. and Abbott, M. (1995), "Andean glacial lakes and climate variability since the Last Glacial Maximum", *Bulletin - Institut Francais d'Etudes Andines*, 24, 539-549



Climate change induced glacier retreat and risk management Glacial Lake Outburst Floods (GLOFs) in the Apolobamba mountain range, Bolivia

SERNAP (2006a), "Apolobamba", Plan de Manejo, technical paper (unpublished)

SERNAP (2006b), "Estrategia de gestión de tierras", Tomo II: Área Natural de Manejo Integrado Nacional, technical document (unpublished)

Singh Khadka, N. (2011), "Quakes could rupture glacial lakes"

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

Tarquino, R. and 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. and 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

Yamada, T. (1998), "Glacier Lake and its outburst flood in the Nepal Himalaya", Tokyo, Japan, Data Center for Glacier Research, Japanese Society of Snow and Ice