



for a living planet

The Cost of Climate Change

The Story of **Thorthormi**
Glacial Lake in Bhutan

WWF's Living Himalayas Initiative



Introduction

Climate change is impacting people, wildlife and habitats around the world. The science is conclusive and the evidence abundant. And nowhere else on Earth has more powerful, violent and heartbreaking visual evidence of climate change than the Eastern Himalayas. Here among the water towers of Asia, catastrophic floods caused by climate change have already washed away villages, killed people and wreaked havoc on livelihoods and wildlife. Sadly, more of these glacial lake outburst floods (GLOFs) will occur as climate change continues -- and one such lake in Bhutan encapsulates the risks and impact of doing nothing.

This publication tells the story of that lake and introduces evidence from across the Himalayas of the price its people are paying for climate change and the consequences of not taking action. It also describes a heroic high-altitude effort currently underway to try and prevent disaster should Thorthormi burst its banks.

Glacial lake outburst floods are catastrophic discharges of water from glacial lakes. As glaciers retreat they leave behind reservoirs of water which grow in size over time. The walls that hold the water in place are structurally unstable and weak and undergoing constant changes. This increases the risk of breach in these walls and a sudden, devastating discharge of large quantities of water.

These GLOF events have increased in frequency in the latter part of the 20th Century, resulting in loss of life, property and livelihoods in Bhutan, India, Nepal and China. Bhutan's most devastating GLOF event was in 1994, when Lugge Tsho, a lake in the same region as the Thorthormi Lake burst, killing 20 people, numerous yaks and damaging dozens of houses, water mills and pasture land. Bhutan has 25 potentially dangerous glacial lakes, including Thorthormi.

Thorthormi Lake could burst at any time, and the consequences would be tragic. Numerous villages would be in the path of the flood and it could even wash away the Punakha Dzong, a stunning 14th Century Buddhist temple that was once the seat of power for Bhutan's King. The effort described in this publication to lower the lake level by five meters is unprecedented, involving a cast of hundreds. Scientists, conservationists, government experts, farmers, villagers and taxi drivers from the city have already withstood extreme weather, high altitude and freezing temperatures to manually dig a channel to lower the lake.

This publication also outlines glacial lakes, floods and other threats posed by melting glaciers throughout the Himalayas. It should serve as a call to action for policy-makers, scientists, governments and all people who care about the state of our planet. Slowing down climate change is only part of the battle. Helping nature adapt to the changes already underway is the other part.

Ice melting on the Khumbu Glacier - Everest region, Nepal



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The Cost of Climate Change

The Story of Thorthormi Lake in Bhutan

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THE STORY OF LUNANA

Lunana, in northern Bhutan is one of the world's most pristine mountain regions, yet un-spoilt by human excesses. It is also one of the most beautiful and least visited landscapes of the world and is renowned as one of the world's most challenging trekking routes due to its altitude, distance, climate and remoteness. Amidst its mystical calmness and mesmerizing façade of serenity and solitude, lies danger. A danger that is silent, sudden and cataclysmic.

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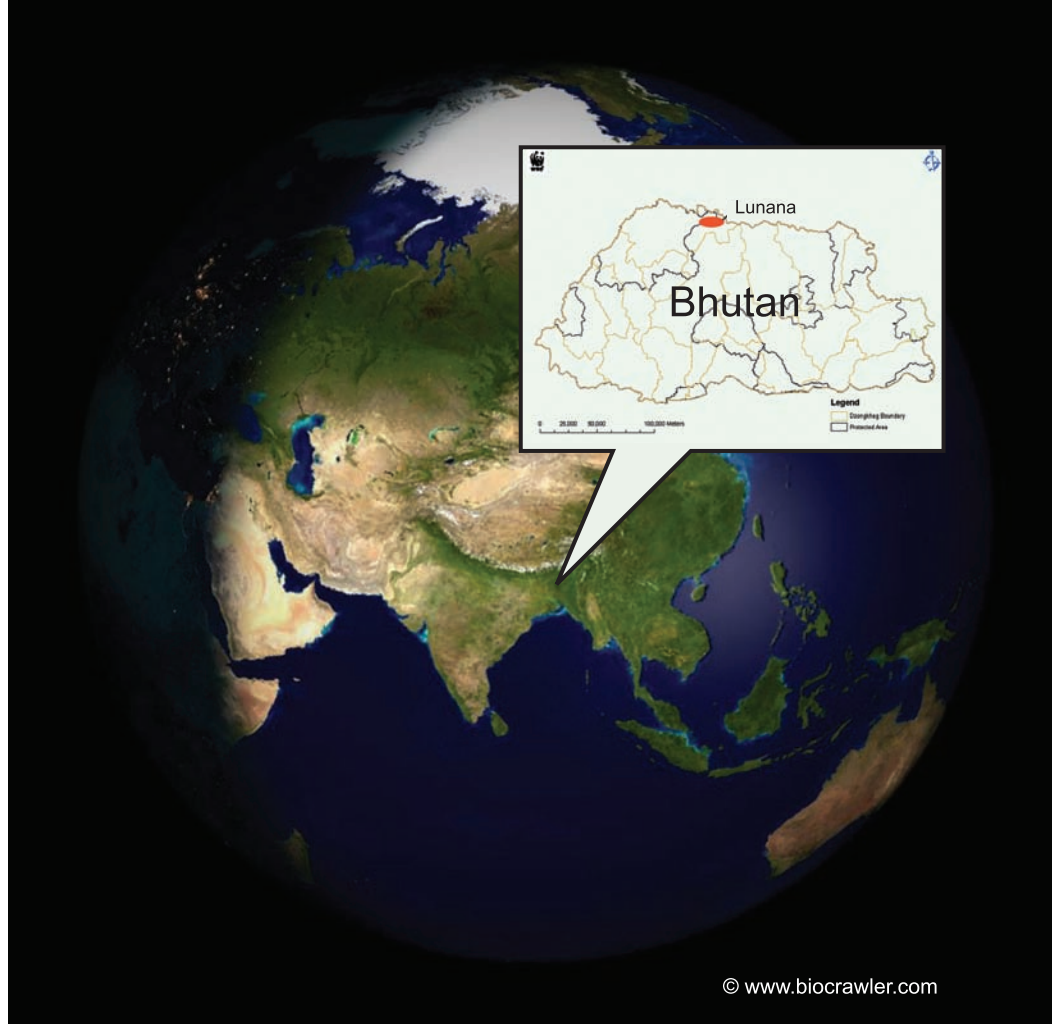
The Lunana area is a basin with altitudes of 4300-4500 m between the main Himalayan divide and mountains and plateau with 5000-5500 m altitudes to the south. The large glaciers are located in the Lunana basin, while smaller glaciers are on plateaus that stretch to the south from the basin. Field observations and investigation by map and satellite images indicate that supra glacial lakes on the glaciers tend to connect with each other and grow to a large lake rapidly. Lunana is seeing this happen since the 1970s due to retreat and/or melting of glaciers. The result of this has been the 1994 glacial lake outburst flood (GLOF) that killed over 20 persons in the downstream area.¹

FACTS

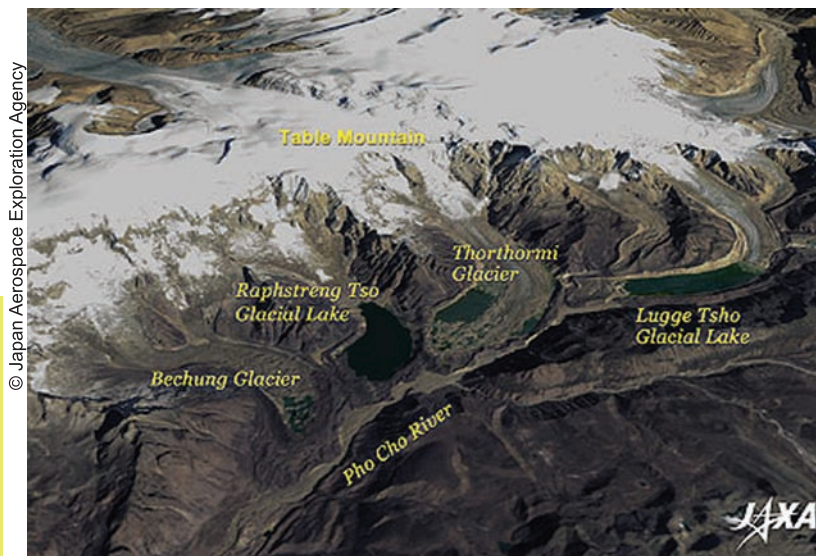
GLOF events have been common phenomena in the Lunana area in the past 50 years and have accelerated in the recent years.

Following the 1994 GLOF, the Bhutanese Government and scientists started monitoring the glaciers, glacial lakes and related phenomena in the Lunana area since 1995. The Bhutan-Japan Joint Research on the Assessment of GLOF started research from 1998 and continues till date.

According to Shuji Iwata et.al 2004, assessment on occurrence of triggers, impact to the lakes and vulnerability of moraine-dams suggests that there are at least 3 potentially dangerous glacial lakes in the Lunana area. They are Luggye Tsho, Raphstreng Tsho and Thorthormi Tsho. These glacial lakes contain large volumes of water, are bound to each other and interact sensitively through water flux and erosion. Constant and regular monitoring of glaciers and glacial lakes is required to prepare necessary mitigation activities.²



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SEEN FROM THE SKY

This natural-colour image of the southern slopes of Bhutan's Table Mountain shows where the 1994 glacial lake outburst flood occurred. Luggye Lake broke through the moraine at the southwest corner and the flood scoured a path down the Pho Chu River. It also shows the Thorthormi glacial lake and the unstable moraine separating it from Raphstreng Lake, to the west.

Raphstreng Lake is roughly 80 metres (260 feet) lower in elevation than the lake forming at the terminus of Thorthormi Glacier and an outburst flood from Thorthormi into Raphstreng could easily cause the lower lake to overflow as well. The combined outpouring of meltwater and rock debris could be even more devastating than the 1994 disaster.³

Thorthormi FACTS

Location: Lunana Gewog. 3.5 Km from Thanza village approx. in the headwaters of Pho Chu River.

Geographical Coordinates: 90°15'02.98"E and 90°16'52.38"E longitude, 28°05'43.46"N and 28°08'43.89"N latitude.


Altitude: 4428 masl

Size: 3.42 sq.km (Largest in Lunana in terms of surface area).

Subsidiary lake I: 106.2 m X 39 m at 4426 masl. 47.8m away from main lake.

Subsidiary lake II: 121.5 m X 101.2 m wide at 4422.5 masl. 125 m away from main lake.

Engineering and Safety Plan document Royal Government of Bhutan 2008.

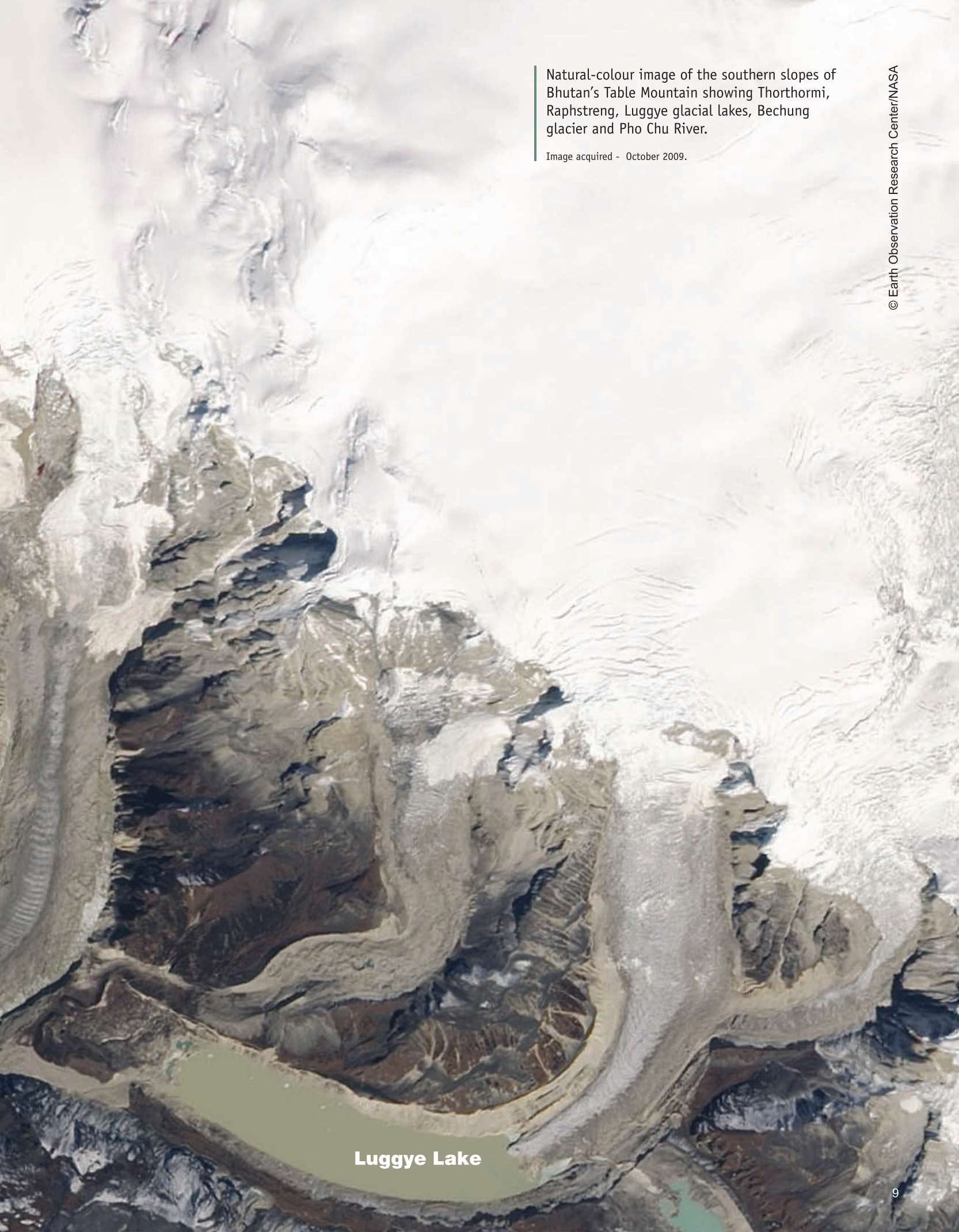


Bechung Glacier

Raphstreng Lake

Thorthormi Lake

Pho Chu River



Natural-colour image of the southern slopes of Bhutan's Table Mountain showing Thorthormi, Raphstreng, Luggye glacial lakes, Bechung glacier and Pho Chu River.

Image acquired - October 2009.

Luggye Lake



Panoramic view of the glacial lakes of Lunana.

The Future Means Anytime

FACTS

The Thorthormi Glacial Lake has a worst-case-scenario outburst projection as early as 2010.

Thorthormi Glacial Lake

Bhutan's most dangerous lake

One of the glacial lakes currently facing a high risk of outburst flooding is Thorthormi Lake in Bhutan's northern Lunana area. Thorthormi glacier had no supra glacial ponds on it during the 1950s but now there are numerous ponds that are enlarging and becoming interconnected. The lake measured only 1.28 sq. km in 2001 (satellite image - Geocover) but is now by far the largest glacial lake in Lunana with a total surface area increase to 3.42 sq. km. Thus the assemblage of supra glacial lakes, on Thorthormi Glacier, has made it one of the most dangerous lakes in Bhutan.



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THORTHORMI In Dire Straits

In Pho Chu basin of the Bhutan Himalayas, the change in size of some glacial lakes has been as high as 800 per cent over the past 40 years.⁴

In the event of an outburst of Thorthormi, there will be far-reaching implications on life, property and infrastructure downstream, which includes three major hydro power projects (one already completed and two in the pipeline).⁵

At present, several supra glacial ponds on the Thorthormi glacier are growing quickly and merging. These lakes pose a threat because of their proximity to other large glacial lakes in the Pho Chu sub-basin where in a worst-case glacial lake outburst flood (GLOF) scenario, they could cascade on to these other lakes with catastrophic consequences.

According to Department of Geology and Mines of the Kingdom of Bhutan, the worst case

scenario of the changes is a combined GLOF of these lakes with resultant outflow of over 53 million cubic metres of water .i.e., three times the volume of the 1994 Luggye GLOF event.⁶

The Thorthormi Lake is located between the Luggye Lake that flooded in 1994 and the Raphstreng Lake. Scientists have raised concerns over the structural strength and stability of the moraine dam between Thorthormi and Raphstreng. The moraine has been decreasing in its size from 70 plus metres at its apex in year 2000 to 32 metres recently.

According to geomorphologist Deo Raj Gurung, in a worst-case scenario, there could be a chain reaction if one of the lakes bursts in Lunana. The Raphstreng Lake where earlier artificial canalizing had been carried out would not be able to hold the water from the Thorthormi in case it leaks due to a moraine wall failure.

Since the last inventory of glaciers and

glacial lakes in Bhutan by the International Centre for Integrated Mountain Development (ICIMOD) in 2001, 106 new glaciers and 120 glacial lakes have formed in the mountains. In the headwaters of the Pho Chu basin alone 16 new glaciers and 82 glacial lakes have been formed in the past 15 years.



© WWF-Canon / Bruce Bunting

Punakha Dzong

It is estimated that 117 buildings, 362 people, 16 historical monuments, a bridge, 5.22 km road and livestock will be affected.

BURST SCENARIO What is at stake?

Half of the fertile Punakha and Wangdi valley would be submerged under water destroying paddy fields and livestock. It may even cause permanent hydrological changes in the area.

The historic Punakha Dzong, built in 1374, the erstwhile seat of monarchy of Bhutan, would be washed away. It is one of the most important monuments of Bhutan's religious, cultural and political history and is enriched with Lhakhangs, more than 200 new religious images and numerous other treasures.

Public establishments like the Khuruthang vocational training institute, Khuruthang weekend market, schools and public spaces along the river side will be washed away.

The upcoming Mega Punatsangchu hydro power projects downstream would face grave dangers.

Bio-diversity in the region will be hit adversely. Huge tracts of forests would be destroyed starting right from the upstream area of Pho Chu River basin. Habitat of the critically endangered White Bellied Heron (*Ardea insignis*) on the Pho Chu River banks will be destroyed along with mega aquatic species like the Mahsheer fish.

Response

The Bhutan National Adaptation Programme of Action (NAPA), issued by the National Environment Commission of the Royal Government of Bhutan has prioritized the Artificial Lowering of Thorthormi Lake in its disaster management strategy.

Scientific Studies/Hazard Mapping/Government Efforts

The first study on glacial lakes of Bhutan was done in the 1960s. However, until the GLOF of 7 October 1994 in Punakha–Wangde valley, the general public had little or no knowledge about the potential dangers of GLOFs. Since then a number of teams were fielded to the area to find ways to mitigate future GLOF hazards.⁷

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 area with special emphasis on Raphstreng and Thorthormi.

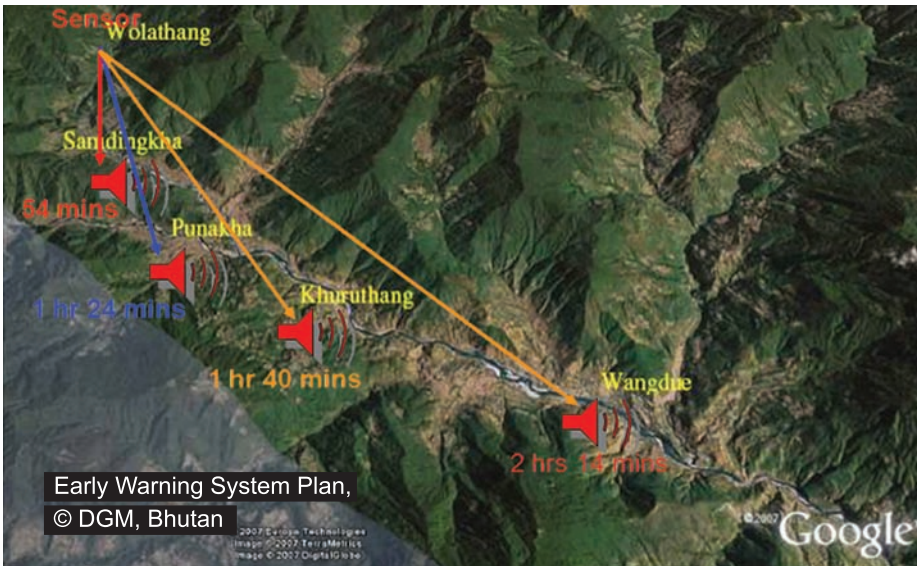
Based on the detailed assessment of hazard potential of Raphstreng and Thorthormi glaciers and its lakes, it was found that there is a probability of a worst case scenario in the near future of a GLOF event – possibly originating in the Thorthormi area, unless urgent mitigation measures were taken.

Subsequently, the Royal Government of Bhutan initiated a project to lower the water levels of two glacial lakes in Lunana to reduce the likelihood of a glacial lake outburst flood. In 1996, the Raphstreng Lake was artificially drained to reduce the hydrostatic pressure on the weakened barrier. The work took two years to complete. In 2006, the Bhutan National Adaptation Programme of Action (NAPA), issued by the National Environment Commission of the Royal Government of Bhutan prioritized the artificial lowering of Thorthormi Lake in its disaster management strategy.

The present Thorthormi Lake Artificial Drainage Project started from 2008 and will continue till 2012. The main objective of the project is to lower the water level of the Thorthormi Lake by excavating an artificial channel-widening of the existing outlet channel.

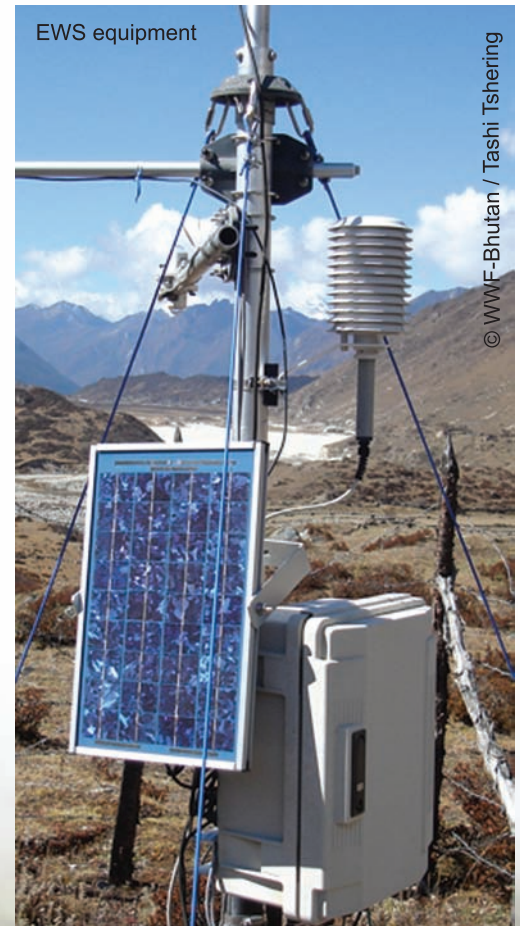


Early Warning Systems in Lunana Region



The first response was to install a manually operated Early Warning System in the Lunana region by the Flood Warning Section (FWS) under the Department of Energy (DoE). In this system, two staff members from the FWS are stationed in the Lunana lake area equipped with wireless sets and satellite telephone. They use these to report lake water levels on a regular basis and to issue warnings to inhabitants downstream (in an event of any indications of GLOF). A number of gauges are

installed along the main river as well as at the lakes. These are monitored at different time intervals depending on the distance of the station from the base camp. The station keep regular contact with other wireless stations in the downstream areas along the Puna Tsang Chu, including the villages and towns of Punakha, Wangduephodrang, Sunkosh, Khalikhola and Thimphu. This obviously is not enough given the threat to life and property downstream.⁸



Flood warning station at Lunana

Averting Disaster

Artificial draining of Thorthormi



Austrian
Development Cooperation



With Thorthormi Lake threatening to burst anytime, the Royal Government of Bhutan along with partners has geared up to negotiate the impending doom by artificially lowering the water level in the lake. The project is currently being implemented under UNDP/GEF Project with funding from LDCF and co-financing from Government of Austria, UNDP, WWF Bhutan and RGoB.

TARGET

To reduce the water level of Thorthormi lake by 5 metres within 3 years.

FACTS

A breach in the moraine wall could mean 53 million cu. mts of water being released into Pho Chu river.

OPERATION THORTHORMI – GROUND ZERO

Securing Thorthormi

A 309 member strong team comprising of locals including 20 women, from neighbouring Laya and Lunana, scientists, technicians, government officials and the Bhutanes Army braved harsh conditions and unpredictable climate high up in the Bhutan mountains to secure Thorthormi. For the daunting task at hand, they were divided into three groups, two of which worked at the feeding channels and the third at the draining channel.

The initial target for 2009 (with working months from July to September) was to reduce the water level in the lake by 1.67 metres. The project began in August with the clearing of boulders that litter the area. The excavated materials of loose rocks and rubble were collected at the sides of the channels to be used for Gabion walls. These walls stand against falling boulders from the moraines that can block the channels in future.

Though there have been no major accidents, the fragility of the project site makes it a very dangerous place to work. "The loose under-lying soil that the moraines are sitting on are subject to landslides at the slightest disturbance and the ignorance of the workers could trigger a mini GLOF so they have to be careful," said Phuntsho Norbu, the site engineering geologist.

Working at an altitude of 4428 metres above sea level, majority of the workers complained about the bitter cold. The incessant rains made working unbearable. A few cases of slight altitude related sickness were reported. Cuts, bruises and minor frost bites were frequent.

Despite their hardships, the workers at Lunana were optimistic that their efforts and contributions will come to fruition by making Thorthormi a safer lake for all.

As of October 28 2009, the water levels in Thorthormi have been reduced by 86 cms against an initial target (July – Sept) of 1.67 metres. The work at the lake was hampered by bad weather and extreme climatic conditions including cyclone 'Aila' that hit the region in May 2009. The heavy rains damaged the access to the site which had to be repaired. The target was thus brought down to 1 metre for the year.

The vigour and determination at the project site in Thorthormi can perhaps be summed up by the enthusiasm shown by 61 year old Rinzi Phub, from the nearby Lhedi village. He is one of the oldest workers at the site. This is the third time that he is

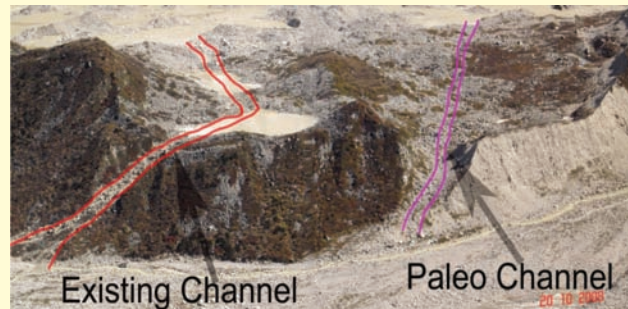
working in the same region for similar project. He also worked for the Raphstreng Tsho project in 1996-98. "At my age and with a blind eye, it has been quite a challenge to work with equal vigour alongside the young workers. The familiarity of the place and the experiences from previous works are an advantage", he said.

Rinzi Phub



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A safe passage

Though there were two possible sites for excavating the channel, one on the orographic right and another on the orographic left of the Thorthormi Lake, the right one was chosen because the largest supra glacial lake of the Thorthormi is located on its head. It is already an active channel, fed by the glacial lakes, with an outlet to the Pho Chu River.

To provide a safe spillway for the water from Thorthormi, the team dug channels leading towards its two subsidiary lakes that feed into the

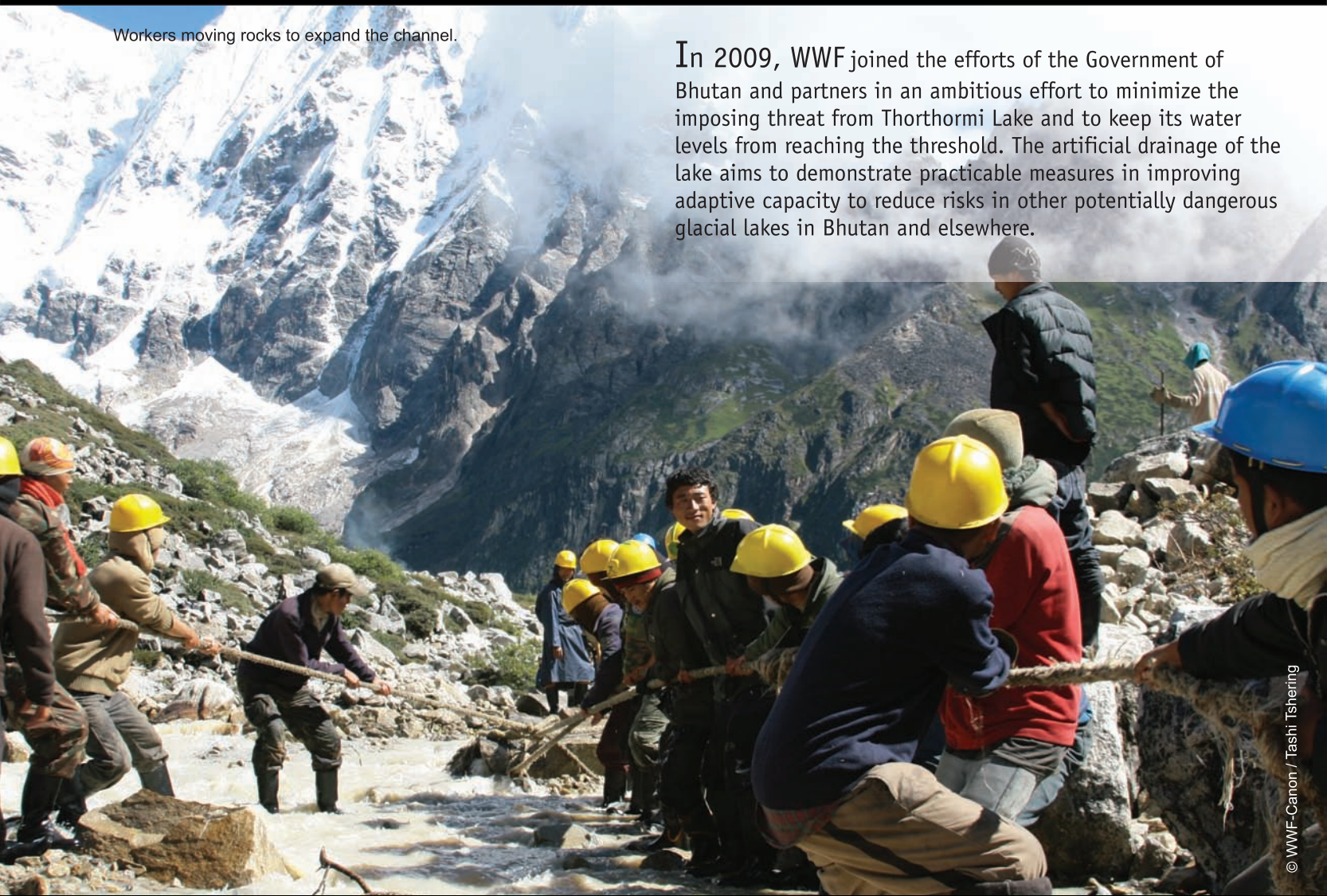
Punakha Pho Chu River. The idea was to prevent the water from flowing into Lake Raphstreng situated 80 metres below Thorthormi. With the wall that separates Thorthormi from Raphstreng only 32 metres thick (at its apex) and continually eroding, extreme care and precision was the order of the day for workers. A breach and failure at this point could mean 53 million cubic metres of water being released into the Pho Chu River with devastating consequences for the low lying valleys of Punakha, Wangduephodrang, Tsirang and Dagana.

Draining of Thorthormi

WWF on the ground

Workers moving rocks to expand the channel.

In 2009, WWF joined the efforts of the Government of Bhutan and partners in an ambitious effort to minimize the imposing threat from Thorthormi Lake and to keep its water levels from reaching the threshold. The artificial drainage of the lake aims to demonstrate practicable measures in improving adaptive capacity to reduce risks in other potentially dangerous glacial lakes in Bhutan and elsewhere.



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VOICES FROM THORTHORMI, LUNANA CLIMATE WITNESS ACCOUNTS



“ The roar that I heard was like none that I had ever heard and I will never forget it, the thought still sends shivers down my spine. ”

Pem Gyem, Thanza village headman, commenting on the unthought-of harm the 1994 GLOF caused to his community.

“ I didn't know of the dire situation that we were facing downstream prior to coming here. I feel humbled to know that what I do here will make a considerable contribution to the aversion of a possible GLOF in the future. ”

Tashi Phuntsho, high school dropout from Thimphu working at Thorthormi project site.



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First hand account from the field

Ploddng on one of the world's most remote and difficult terrains, WWF team members along with a team of 309 embarked on a journey that would keep them away for over 20 days of strenuous labour. The destination – Thorthormi Lake at Lunana, situated at an altitude of 4428 masl in the northern reaches of Bhutan. At this altitude the air gets thin and freezing cold. To reach this lake and work requires exceptional courage and determination.



© WWF-Bhutan / Tashi Tshering

4th August, 2009, 10:30 am: This day marked the start of one of the most difficult, yet pertinent climate change adaptation project in the history of the Himalayas. The artificial drainage of Thorthormi Lake kick started. WWF Bhutan communications team along with the Bhutan Broadcasting Services and the National Television visited the project site to document the progress there.

The sudden rain in May this year that caused damages all across the country delayed the start of the work at Thorthormi by almost a month. The access to the site was damaged and had to be repaired. "Despite the initial delay, the work is progressing smoothly and picking up speed by the day," said Karma Toeb, geologist and Project Head. Till the WWF team was at the site, only 10 cm of the projected 1 metre water level drainage for this year had been achieved. But the project head assured that the work would be stretched beyond the planned deadline to catch-up for the lost time. The total volume of material to be excavated this year was 7273.90 cubic metres.

Workers from all the 20 districts of Bhutan, from all walks of life, worked together to make this project a success. Though all of them came with their own different reasons, they were driven by a single crucial goal - to make Thorthormi a safer lake.

All along the way to the site we could see the after effects of the dreadful 1994 GLOF. In addition, we encountered the damages that the recent May rains caused. Gentle streams had swelled into big gushing rivers, leaving an aftermath of debris and uprooted trees.

The work continued till the weather turned extreme in October. Winter in Lunana is unforgiving. It receives 5-6 feet of snow every year. Many hapless yaks are lost to both cold and predators like the snow leopard. The area remains cut off from the rest of the world till May.

The team members had to endure altitude sickness - especially while crossing Ganglakarchung - the highest pass at 5300 masl. Landslides and lost trails were a frequent problem. Some of us even left our



DNA in the countless leeches that attacked us. The team also had to make new trails and even repair a bridge at Keona. On our way back, we found a dead horse near the Ganglakarchung pass that solemnly reminded us of the dangers that the altitude and trail poses.

By Tashi Tsering, WWF Bhutan.



© WWF Bhutan

“ I can still hear the cries of those helpless children before they were finally washed away. ”

Yangdey Gyem, commenting on the loss of 4 lives (a mother and her 3 children) in the wake of the 1994 GLOF.

“ The three year project will change the socio-economics of the place. ”

Project Manager, commenting on the creation of job opportunities due to the project.



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The Silent Menace

Glacial lake outburst flood is a sudden discharge of large volumes of water contained within a glacial lake due to structural instability and damage in the lake perimeter.

Seen from the air, glacial lakes are tranquil bodies of water nestled in between rugged alpine slopes. They are in fact, held in place by loosely agglomerated rocks and sediments called moraines. When moraines fail due to breaches in its walls, they pose great threat of catastrophic discharges of huge amounts of water that can cause irrecoverable damage to downstream and low lying areas. This can happen due to erosion, a buildup of water pressure, an avalanche of rock or heavy snow, an earthquake or cryoseism, volcanic eruptions under the ice, or if a large enough portion of a glacier breaks off and massively displaces the waters in a glacial lake at its base.⁹

Glacial floods are a regular occurrence in the Himalayan region with varying degrees of socio-economic impact. While a precise forecasting of the socio-economic damages has yet to be made, the bursting of Thorthormi could be quite extensive in terms of destruction of villages, agricultural lands, roads, bridges, hydropower, trekking trails as well as tragic loss of human lives and property. This would result in huge developmental setbacks for Bhutan.

What happens during a GLOF event?

Glacial lakes come in various sizes, but may hold millions of cubic metres of water. Failure to contain this water can result in catastrophic discharge over a time span of minutes to days. Peak flows as high as 15,000 cubic metres¹⁰ per second have been recorded in these events, suggesting that the 'V' shaped canyon of a normally small mountain stream could suddenly develop an extremely turbulent and fast-moving torrent some 50 metres deep. On a downstream floodplain, it suggests a somewhat slower inundation spreading as much as 10 kilometres wide. Both scenarios pose horrific threats to life, property and infrastructure.

The Aftermath

GLOF events are severe geomorphological hazards and their flood waters can wreak havoc along its path. A lot of the damage during GLOF events is associated with the large amounts of debris carried in the flood waters. They have resulted in many deaths, as well as causing irrecoverable damage.

The 1964 GLOF event of China, the bursting of Zhangzhangbo Lake in 1981 and the Dig Tsho GLOF of 1985 (Nepal) are classic examples of GLOFs in the Himalayan region that resulted in loss of lives and millions of dollars worth of infrastructural damage in their wake.

HIMALAYAN GLACIERS

Fulfilling the water needs of roughly 10% of the world's population, the Himalayas are the Water Towers of Asia and the most important source of freshwater in the region. The lofty Himalayan mountains encompass 5 countries and a vista of cultural and biological diversity of landscapes therein.

The glaciers of the greater Himalayan region are nature's renewable storehouse of fresh water from which hundreds of millions of people downstream have benefited for centuries. These high frozen reservoirs release their water at the top of the watersheds of the ten major rivers in the region. These rivers wind their way through thousands of kilometres of grazing, agricultural and forest lands and are used as renewable sources of irrigation, drinking water, energy and industry, serving some 1.3 billion people who live in the great river basins. (ICIMOD).¹¹

The Himalayan region is intrinsically linked to global atmospheric circulation, hydrological cycle, bio-diversity and water resources. It has about 15,000 glaciers - nature's renewable storehouse of fresh water. However, in the face of accelerated global warming the glaciers in the Himalayan region are retreating at as high a rate as 30-60 metres every ten years leading to accumulation of increasing amounts of water in mountain-top lakes. (RGLOF project UNDP/ECHO)¹²

The total number of glaciers in the region is still unknown, as is the number and location of potentially dangerous glacial lakes. (cit. ICIMOD web).¹³ A study carried out jointly by ICIMOD, UNEP and Asia-Pacific Network for Global Change Research (APN) between 1999 and 2003 estimated about 15,000 glaciers and 9000 glacial lakes in Bhutan, Nepal, Pakistan and selected basins of China and India (Mool et al. 2005).¹⁴ With such a high concentration of captive water and ice the Himalayan region is refer to as the 'Third Pole' (Dyhrenfurth 1955).¹⁵ Glacier runoff thereby is an important freshwater resource in arid regions as well as during the dry seasons in monsoonal affected regions (Barnett et al. 2005).¹⁶



FACTS

Peak flows as high as 15,000 cubic metres per second have been recorded in a GLOF event.

WHAT IS A POTENTIALLY DANGEROUS GLACIAL LAKE ?

On the basis of field and satellite observations, geomorphologic disposition, glacial activity and past records, glacial lakes are identified as potentially dangerous. The study of topographic maps, satellite images and field information showed that most of the identified potentially dangerous lakes started to form more than 40 years ago (ICIMOD).¹⁷ The closer a lake is in proximity with a glacier, the more potentially dangerous it becomes. Hence, lakes have been classified as potentially dangerous according to their distance from the glacier. Among other factors, the type of a glacial lake determines its potential for danger. Moraine-dammed lakes are considered the most dangerous due to structural instability and susceptibility to breach due to external factors.

Nature's Ticking Time Bombs



Himalayan Glacial Lakes

Central Asia with an estimated total ice cover of 114,800 sq. km has as its dominant mountain range the Himalayas, where most of the glaciers occur (33050 sq. km). The Himalayas are the highest mountain range of the world and extends from the Nanga Parbat (8126 masl) in the NW over 2 500 km to the Namcha Barwa (7782 masl) in the SE with a north-south extent of 180 km (Burga et al. 2004).¹⁸

Global warming has had a significant impact on the high mountainous glacial environment. Glaciers are melting leaving behind a large number of glacial lakes. An increase in the rate of ice and snow melt leads to rapid accumulation of water in these lakes bound by weak moraine walls. A sudden discharge of large volumes of water caused by a breach in the walls causes glacial lake outburst floods (GLOFs) downstream. Such floods result in heavy death tolls and destruction of natural resources and valuable property.

Historical Evidence

Himalayan glaciers have been in a state of general retreat since 1850 (Mayewski & Jeschke 1979) and the rate of retreat is accelerating. But a dramatic increase in the retreat has been observed in the last three decades.

GLOFs IN THE PAST

EXAMPLES AND CASE STUDIES

In South Asia, particularly in the Himalayan region, the occurrence of GLOF events have led to loss of lives, property and infrastructure. In Bhutan, India and Nepal, these events have had varying degrees of socio-economic impacts in the past and continue to threaten bio-diversity, imperil livelihoods and hinder economic development.

BHUTAN

Majority of the glaciers in Bhutan fall into the primary classification of mountain glaciers with simple basins with their major source of recharge being from snow or avalanches with a marked rate of retreat of 30-40 metres annually. Glaciers in the Bhutan Himalayas generally occur above the elevation of 4,000 masl. There are 677 glaciers altogether within the territory of Bhutan. They cover an area of 1,316.71 sq. km with approximately 127.25 cubic km of ice reserves.²⁰

GLOFs are among the most serious natural hazards in Bhutan. They threaten the lives and livelihood of people living in the valleys and low lying river plains. There are 2,674 glacial lakes in Bhutan, of which 562 are associated with glaciers. Hazards due to GLOF, flash floods and landslides are likely to increase in intensity as a result of impacts of climate change.

There have been several cases of GLOFs in Bhutan, but only one has been recorded in detail. All major GLOFs of 1957, 1969 and 1994 originated from glaciers in Lunana area of north-western Bhutan.

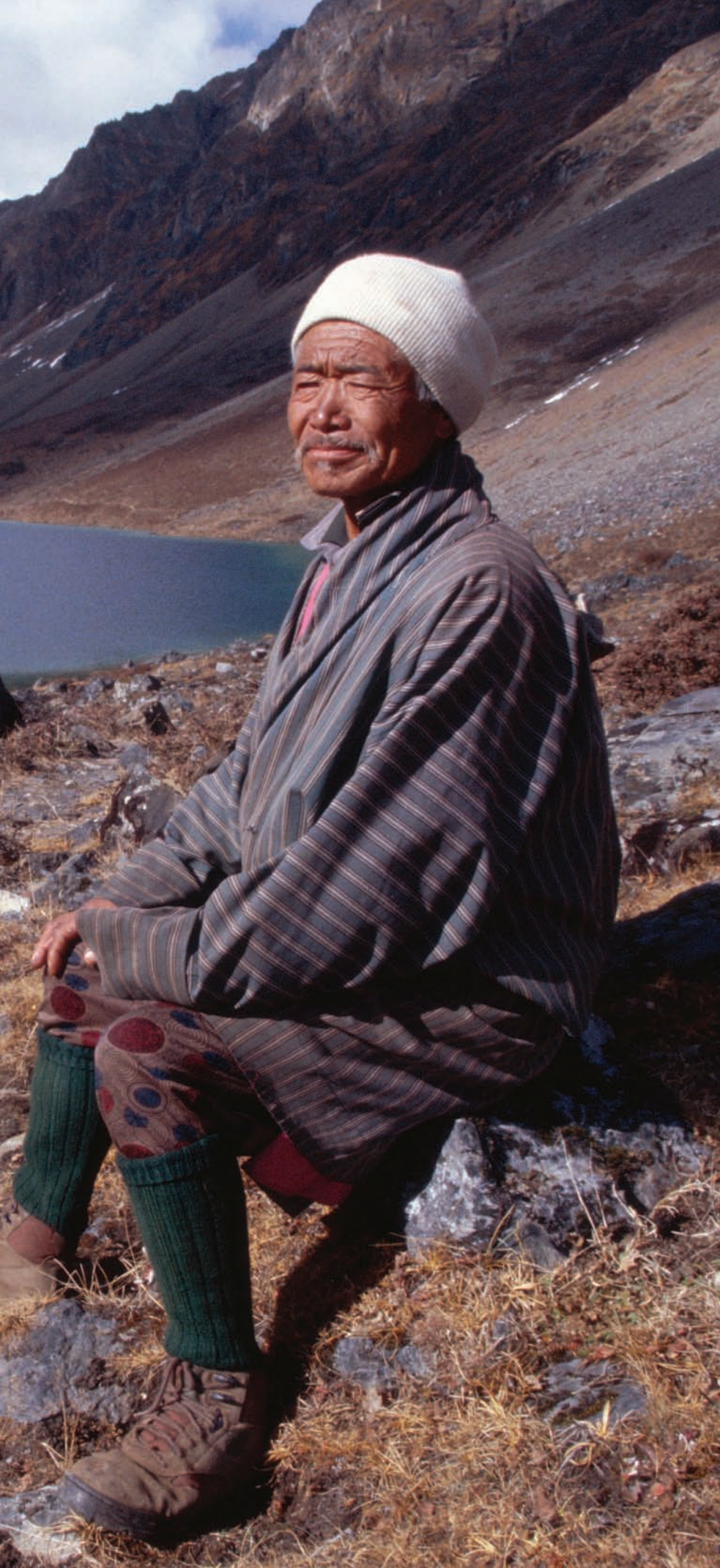
1957 GLOF: The 1957 GLOF affected the Punakha-Wangdue valley, which destroyed part of Punakha Dzong. Gansser (1970) attributed this flood to the outburst from Tarina Tsho, western Lunana.²¹

1960 GLOF: This flood also destroyed part of Punakha Dzong due to the bursting of some lakes in eastern Lunana. It is said to have lasted for five days and there are no written records of this flood.²²

1994 GLOF - Luggie Tsho glacial lake outburst flood: The partial breaching of lake Luggye Tsho on 7 October 1994 caused a catastrophic GLOF, the memory of which is still fresh in the minds of people who witnessed it. This GLOF will in all likelihood go down in the history of floods in Bhutan as the most catastrophic event ever recorded both in terms of its magnitude and in terms of the damage it wreaked on the lives, property and infrastructure of the people downstream. The severity of this event prompted the Department of Geology and Mines (under the Ministry of Trade and Industry, Royal Government of Bhutan) to initiate a number of research activities on glaciers and glacial lakes in the country.²³

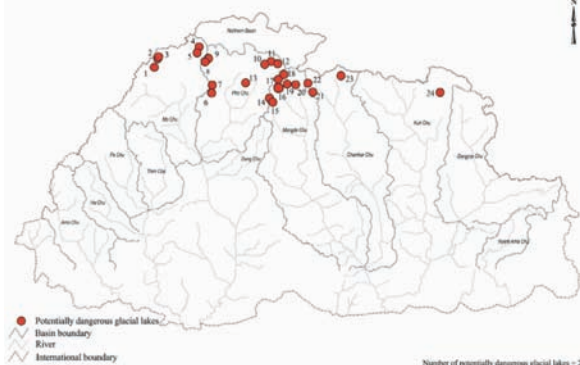
This GLOF caused loss of 20 lives and property along the Punakha-Wangdue valley and damaged part of Punakha Dzong. From the survey conducted on 20-23 October 1994, a total of 91 households were affected by the flood in the Lunana region. As a result, 12 houses were damaged, 5 water mills washed away, 4 bridges destroyed and 816 acres of dry land were damaged.²⁴

There was a major damage to pasture lands upon which local people were dependent to herd their yaks. A total of 965 acres of pasture land was washed away or covered by sand and silt. Livestock including 16 yaks were washed away by the flood.²⁵



POTENTIALLY DANGEROUS GLACIAL LAKES IN BHUTAN

Among the 562 glacier associated glacial lakes in Bhutan, 174 are at a distance of less than 50m. There is no complete and comprehensive inventory of glaciers, glacial lakes and GLOFs in Bhtan. However, the 2001 ICIMOD and UNEP report (Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region - Bhutan) lists 2, 674 glacial lakes in Bhutan. Of these 24 are potentially dangerous. With the inclusion of Thorthormi Lake this number of potentially dangerous lakes in Bhutan has increased to 25. (Engineering and Safety Plan document-RGoB)



Potentially dangerous glacial lakes in Bhutan

- Chu Sub Basin: 9
- Mo Chu Sub Basin: 5
- Chamkhar Chu Sub Basin: 3
- Kuri Chu Sub Basin: 1
- Mangde Chu Sub Basin: 7

source ICIMOD 2001

GLOFs IN THE PAST

EXAMPLES AND CASE STUDIES

INDIA

The Indian Himalayan region is home to over 5,160 glaciers. They play a crucial role in shaping and influencing the environmental conditions in India. Siachen, Gangotri, Zemu, Milam, Bhagirath Kharak and Satopanth are some of the important glaciers located in the Indian Himalayan region.

The Indian Himalayan glaciers are broadly divided into the three-river basins of Indus, Ganga and Brahmaputra. The Indus basin has the largest number of glaciers (3,538), followed by the Ganga basin (1,020) and then the Brahmaputra basin (662).

Notable GLOF events in Indian Himalayas

Thirty-five destructive GLOF events have been recorded in the Upper Indus River system in the past two hundred years, but there have been few catastrophic floods in the recent past (WECS 1987). A GLOF from the Shyok area in August 1929 in the Indus River system extended 1,300 km downstream to Attock and had a discharge greater than 15,000 cubic metres/sec (WECS 1987).²⁶

1997: Flash floods washed away six bridges in the Sutlej basin and Kinnaur district was completely cut off.

2000: Flash floods occurred in the Sutlej river basin.

2005: The Parechu river lake in Tibet burst causing loss of life and heavy destruction of livelihoods and infrastructure, particularly in Kinnaur and the eastern part of Shimla districts in Himachal Pradesh. The impact of such flash floods is further accentuated by the fact that the numerous tributaries of the Sutlej flow through narrow fragile valleys and Khuds, prone to constant land slides and mud flows.²⁷

POTENTIALLY DANGEROUS GLACIAL LAKES IN INDIA

Of the states that consist of glaciers and glacial lakes in India, studies indicate high risk areas in the northern states of Himachal Pradesh and Sikkim.

Himachal Pradesh

Himachal Pradesh is one of the most hazard prone states in India. It is a region of high seismic activity. It is frequented by earthquakes, cloudburst flash floods, landslides, landslide induced river dam bursts, avalanches and forest fires.

There are altogether 156 glacial lakes identified in the northern region of Himachal Pradesh. Among them 141 have been associated with glaciers of which 49 are at a distance of less than 50m.²⁸ Out of them 16 potentially dangerous lakes have been listed below. Among these lakes, moraine-dammed lakes and blocked lakes are susceptible to breach out easily due to different phenomena. When supra glacial lakes start merging with one another to form a larger lake and finally change into a moraine-dammed lake, they become dangerous.

Sikkim

14 glacial lakes have been identified as potentially dangerous lakes in the Sikkim Himalayas. These have been classified using different criteria and the use of satellite data. Among the identified potentially dangerous glacial lakes, 11 are moraine-dammed lakes, two are blocked lakes and one is a valley lake. 11 of these lakes have past burst records.²⁹

Potentially dangerous glacial lakes

Himachal Pradesh - 16

Beas Basin: 5

Satluj River Basin: 3

Ravi River Basin: 1

Chenab River Basin: 5

Takling la Sub-basin: 2

Sikkim - 14

source ICIMOD 2003, 2004

GLOFs IN THE PAST

EXAMPLES AND CASE STUDIES

NEPAL

The Nepal Himalayas harbour 3,252 glaciers and 2,323 lakes above 3,500 masl. They cover an area of 5,323 sq. km with an estimated ice reserve of 481 cu kms. (ICIMOD)

Records from 1935, show 15 GLOF events recorded in Nepal and 6 in the Tibet Autonomous Region of China (with consequences in Nepal).

Examples in Nepal include: Nare (1977), Nagma Pokhari (1980), Dig Tsho (1985), Chhubung (1991) and Tam Pokhari (1998). The Tibetan cases include: the Zhangzhangbo (1981) and Jinco (1982). Some Bhutanese GLOF include the Luggye Tso GLOF (1994), the Zhangzhangbo (1981).³⁰

The Dig Tsho Disaster of 1985

Perhaps the Dig Tsho outburst of 1985 will go down in the annals of glacial disasters in the Himalayas as the most prominent and one that triggered renewed efforts in studying GLOFs in the region. On August 4, 1985 Dig Tsho glacial lake burst, emptying its 6-10 million cubic metres of water in 4-6 hours (Vuichard and Zimmerman 1986, 1987.)³¹

The lake discharged water at an average of 500 cubic metres/second. It was later calculated that it burst initially with a discharge of 2000 cubic metres/second. The resulting catastrophic deluge took lives and eroded the right bank of Bhote-Dudh Koshi at the Namche Small Hydel Project site. Shock waves as high as 5-10 metres developed at obstructions such as river banks, constrictions, bends and boulders. Velocities were exceptionally high. The site of civil structures of Namche (Thame) Small Hydel Project (estimated cost of US \$1.5 million), were completely destroyed by the GLOF (WECS 1987).³² Besides the Hydel Project, the GLOF destroyed 14 bridges, trails, cultivated land and swept away many lives along the valley. (ICIMOD).³³

POTENTIALLY DANGEROUS GLACIAL LAKES IN NEPAL

An inventory carried out by ICIMOD and UNEP/EAP-AP lists 2,315 glacial lakes in Nepal of which 20 are potentially dangerous (ICIMOD and UNEP/EAP-AP 2000).³⁴ Field studies of six glacial lakes (Tsho Rolpa, Imja, Thulagi, Lower Barun, Dig Tsho and Tam Pokhari) in Nepal have been carried out by different organizations.

Potentially dangerous glacial lakes in Nepal

Tamor Sub-basin: 2

Arun Sub-basin: 1

Dudh Koshi Sub-basin: 12

Tama Koshi Sub-basin: 1

Budhi Gandaki Sub-basin: 1

Marsyangdi River Sub-basin: 1

Kali Gandaki Sub-basin: 2

source ICIMOD 2001

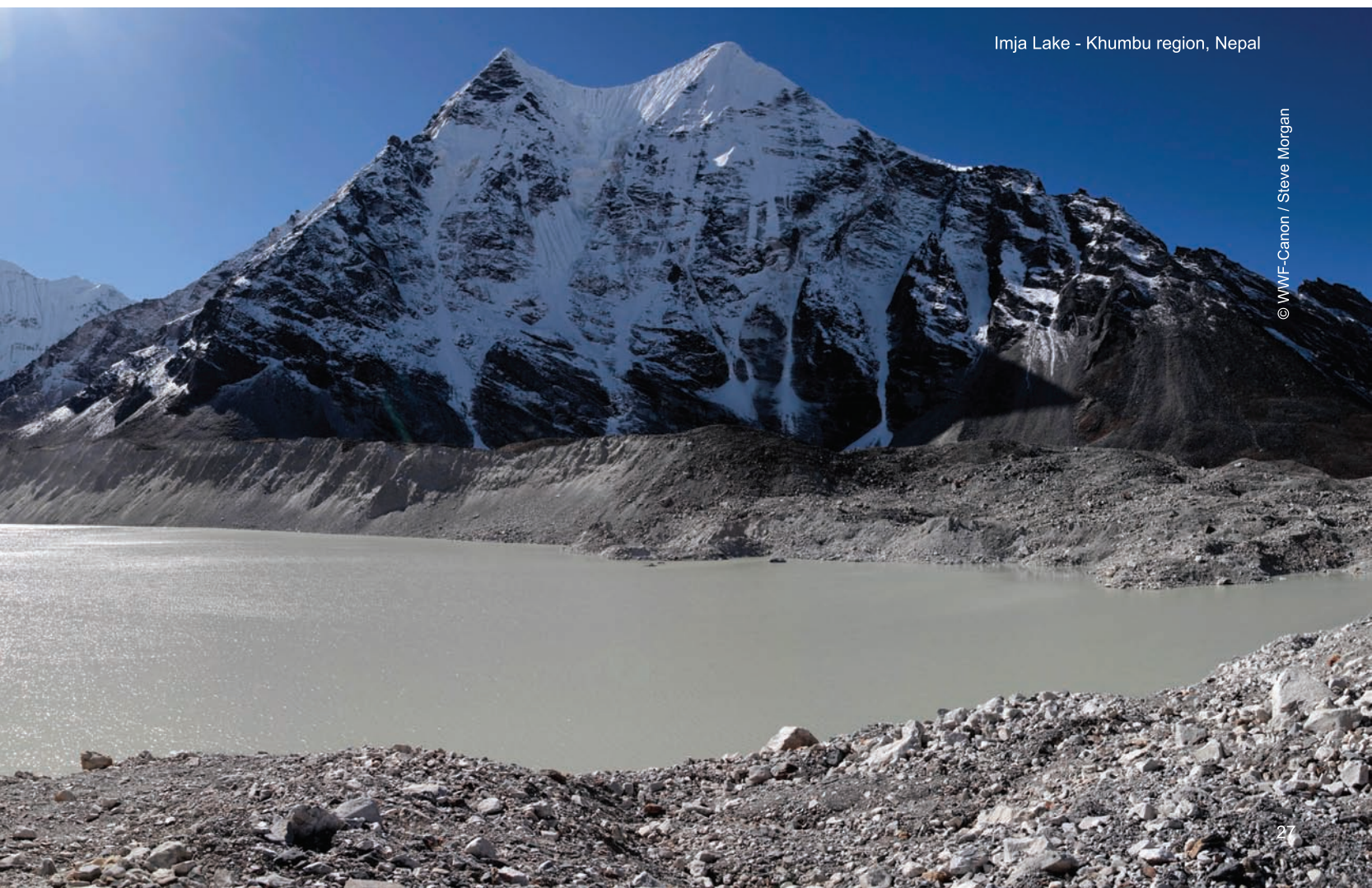
Which glacial lake next...



As this publication clearly notes, the Himalayas, its people and wildlife, are suffering more than most from the impacts of climate change. While heroic efforts like those at Thorthormi Lake can help relieve the pressure and avert immediate disaster, they are not the long-term answer. Threats from glacial lakes will intensify as melting increases. At least 80 lakes in the Himalayas are today classified as potentially dangerous. A Thorthormi - like effort cannot be done in every one.

The GLOF threat only compounds the other threats to the region's rich tapestry of life. The Himalayas have a rich cultural and spiritual heritage and immense biodiversity that sustains the lives of millions of people. But threats abound in this fragile landscape – population growth, poaching, unplanned development, agricultural expansion, deforestation and climate change.

We must give nature a helping hand to tackle the changes and the challenges. At the international level, governments must agree to strong binding commitments to reduce greenhouse gas emissions. At the local level, bold, innovative adaptation projects such as the one at Thorthormi must be attempted, with financial and technical aid from the richer countries. These projects are expensive, but doing nothing will prove even more expensive in both human and economic terms.



Imja Lake - Khumbu region, Nepal

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The bed of Khumbu glacier, Everest region. As seen from Tuckla pass en route Labouche.



Valley above Pheriche in the Himalayas - Nepal



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