AN OVERVIEW OF NATURAL HAZARD IN RELATION TO GLACIERS & GLACIAL LAKES IN BHUTAN

Presentation by:
Dorji Wangda
(Director)
Dept. of Geology & Mines
Ministry of Trade & Industry
Thimphu: BHUTAN

- Situated in the eastern Himalayas between latitudes 26.7º to 28.4º N and longitudes 88.7º to 92.2ºE
- Bordered by the Tibetan Plateau of China in the north and the Indian States of Sikkim in the west, West Bengal, and Assam in the south, and Arunachal Pradesh in the east

GEOGRAPHICAL LOCATION OF BHUTAN

PHYSICAL FEATURES

- Area – 46,620 Sq. Km
- The rugged mountainous terrain has elevation ranging from 200m asl to above 7000m asl within a distance of <175 km
- Area above 4200m asl covers 20.5% of the total land

CLIMATE

- Climate in Bhutan is dominated by a southwestern monsoon, which originates from the Bay of Bengal
- Climately Bhutan is divided into three broad zones: subtropical in the southern foothills, temperate in the inner hills, and alpine in the northern part
- Southern foothills are hot and humid during the summer months and quite cool in winter

  Inner hills are cold in winter and warm in summer with a pleasant spring and autumn with mild temperatures

RIVER SYSTEM

The rivers of Bhutan can be divided into six major river basins mostly flowing from north to south.

SEISMICITY

Bhutan is prone to earthquakes and lies in zones 4-5 on the Richter scale. Although there have been earthquakes in the past, there are no documented records of magnitude or damaged caused.

NATURAL RESOURCES

Flora

72% of the country covered by forest with varied species of plants including medicinal plants

Fauna

Over 165 species of animals including golden langur, takin, blue sheep, snow leopard, red panda, Himalayan black bear, wild pig, musk deer and rare black-necked crane

Mineral Resources

Industry based minerals such as dolomite, limestone, gypsum, marble, coal, quartzite, talc etc.

Hydropower Resources

Most of the rivers originate from glacial lakes (glaciers melt water) and the altitude difference provides huge potential for hydropower development. The Power Master Plan estimated hydropower potential of 20,000 MW from the rivers in the country.

GLACIERS

According to the recent inventory on glaciers done by Dept. of Geology & Mines in collaboration with ICIMOD, Nepal, there are about 667 glaciers and 2674 glacial

lakes in Bhutan alone.

GLACIAL INVENTORY

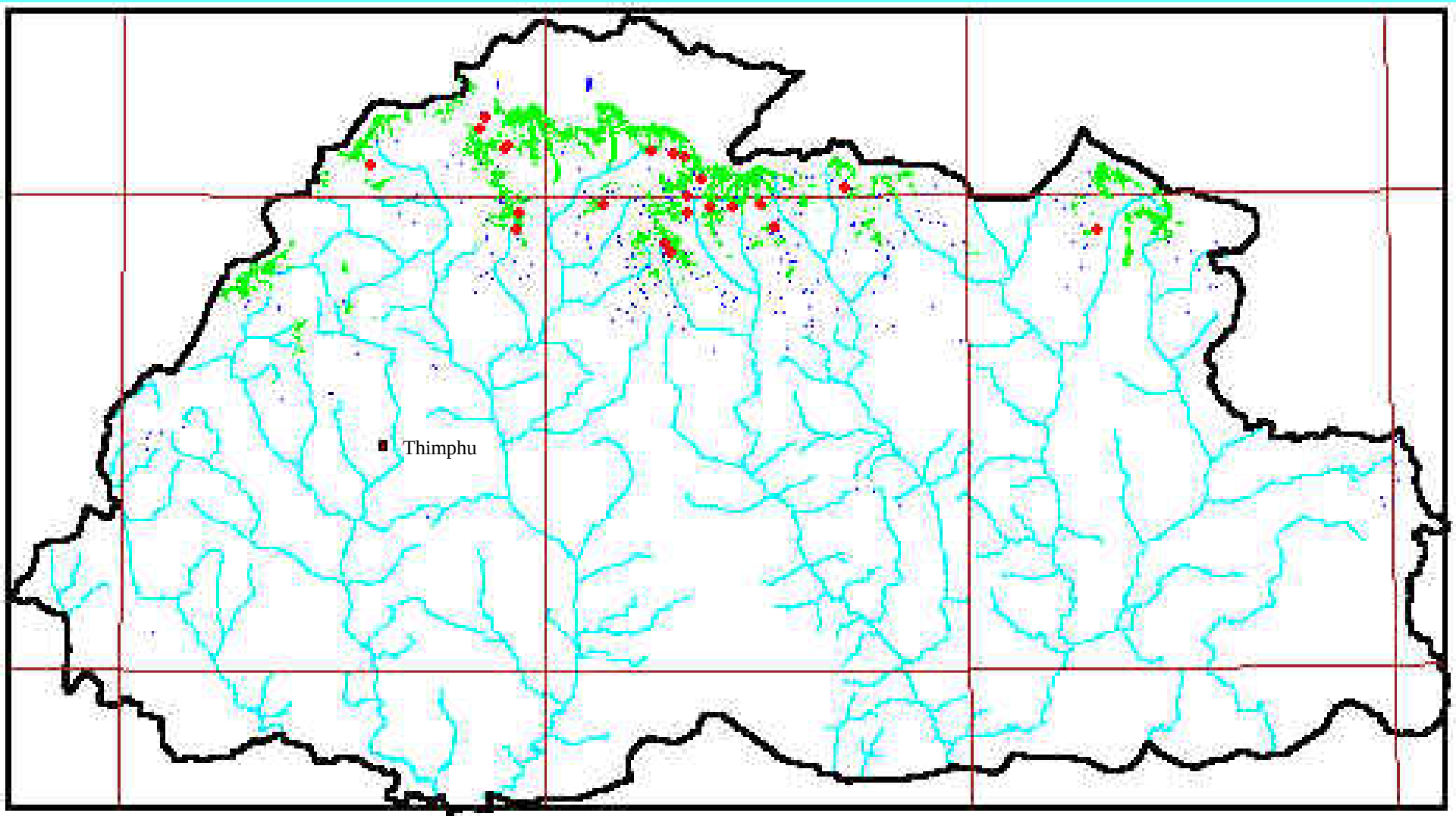
Glaciers Inventory was done to:

- understand the GLOF phenomena and monitor GLOF events on regular basis
- establish effective early warning system and monitor GLOF hazards using GIS and RS

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

From the present study, 24 glacial lakes have been identified as potentially dangerous based on the analysis of data using different criteria and the study of topographic maps and satellite images.

- Potentially Dangerous Glacial Lakes in Bhutan



Potentially dangerous glacial lakes in Bhutan

1. Mo Chu Sub-basin

Sl. No.	Lake No.	Name of Lake	Latitude	Longitude	Altitude (masl)	Length (m)	Area (m^2)
1.	Mo_gl200	Kab	28º04’00.00	89º35´05.50	4280	285	52090.11
2.	Mo_gl201		28º06´15.60	89º36´55.60	4080	325	30863.71
3.	Mo_gl202		28º07´44.40	89º36´31.60	4380	325	34287.76
4.	Mo_gl234	Setang Burgi	28º10´06.00	89º51´21.10	4480	795	232744.52
5.	Mo_gl235		28º08´35.40	89º50´43.00	4960	565	150131.36

2. Pho Chu Sub-basin

Sl. No.	Lake No.	Name of Lake	Latitude	Longitude	Altitude (masl)	Length (m)	Area (m^2)
6.	Pho_gl84		27º56´48.53	89º55´14.03	5040	660	214078.18
7.	Pho_gl148		27º58´09.42	89º56´16.69	4880	1285	454510.02
8.	Pho_gl163		28º06´06.43	89º54´11.83	4280	1200	369572.13
9.	Pho_gl164	Tarina	28º06´37.22	89º54´37.81	4320	1095	280550.42
10.	Pho_gl235	Raphstreng	28º06´43.56	90º14´03.65	4360	550	145948.56
11.	Pho_gl210	Luggye	28º05´00.34	90º18´28.58	4600	1980	769799.72
12.	Pho_gl211		28º05´40.45	90º19´11.95	4710	650	141975.78
13.	Pho_gl313		27º59´58.72	90º07´18.86	5030	205	222134.80

3. Mangde Chu Sub-basin

Sl. No.	Lake No.	Name of Lake	Latitude	Longitude	Altitude (masl)	Length (m)	Area (m^2)
14.	Mang_gl99		27º54´22.13	90º16´45.88	4960	605	192607.29
15.	Mang_gl106		27º53´19.45	90º17´33.94	5040	1480	868294.42
16.	Mang_gl270		27º58´09.32	90º20´06.98	5280	850	239778.31
17.	Mang_gl285		28º00´20.90	90º19´50.77	5390	795	341412.93
18.	Mang_gl307		28º02´21.01	90º21´58.87	5240	1800	767429.06
19.	Mang_gl310		27º58´49.87	90º23´05.53	5200	575	200746.06
20.	Mang_gl385		27º58´58.53	90º26´21.90	5086	535	466125.34

4. Chamkhar Chu Sub-basin

Sl. No.	Lake No.	Name of Lake	Latitude	Longitude	Altitude (masl)	Length (m)	Area (m^2)
21.	Cham_gl198		27º56´22.27	90º32´15.91	5046	1495	624669.81
22.	Cham_gl232		27º59´11.33	90º30´31.42	5200	565	205146.23
23.	Cham_gl383		28º01´25.91	90º42´31.77	4840	2645	1035131.5

5. Kuri Chu Sub-basin

Sl. No.	Lake No.	Name of Lake	Latitude	Longitude	Altitude (masl)	Length (m)	Area (m^2)
24.	Kuri_gl172		27º55´47.56	91º18´08.77		850	161706.43

Importance & Implication of Glaciers

- Water Resources (Hydro Power, Drinking, irrigation)
- Natural Disaster (GLOF, Avalanches)

HISTORY OF GLOF IN BHUTAN

- 1950s -
- 1960s -
- 1994 – Luggye Tsho

MITIGATION & RESEARCH ACTIVITIES CARRIED OUT

- 1967 – Gansser's expedition & identification of dangerous glacial lakes in Lunana region
- 1974 & 1981 – Aerial reconnaissance survey by Geological Survey of India in Lunana area
- 1986 – Joint DGM-GSI Lunana Expedition

- 1995 – Expedition to Lunana by Indo-Bhutanese team to identify cause and effect of 1994 GLOF
- 1996 (July-August) – Expedition to Roduphu glacial lake by multidisciplinary team (NEC, DGM, DoR, Bhutan Survey)

- 1996-1998 – Mitigation Measures for Raphstreng Tsho in collaboration with GOI
- 1998 – Joint Bhutan-Japan Project for hazard risk assessment for GLOF

- 1999 (April-May) -Risk Assessment of Upe Tsho & Tsokar Tsho in the Head Waters of Chamkhar Chhu, Bumthang by DGM.

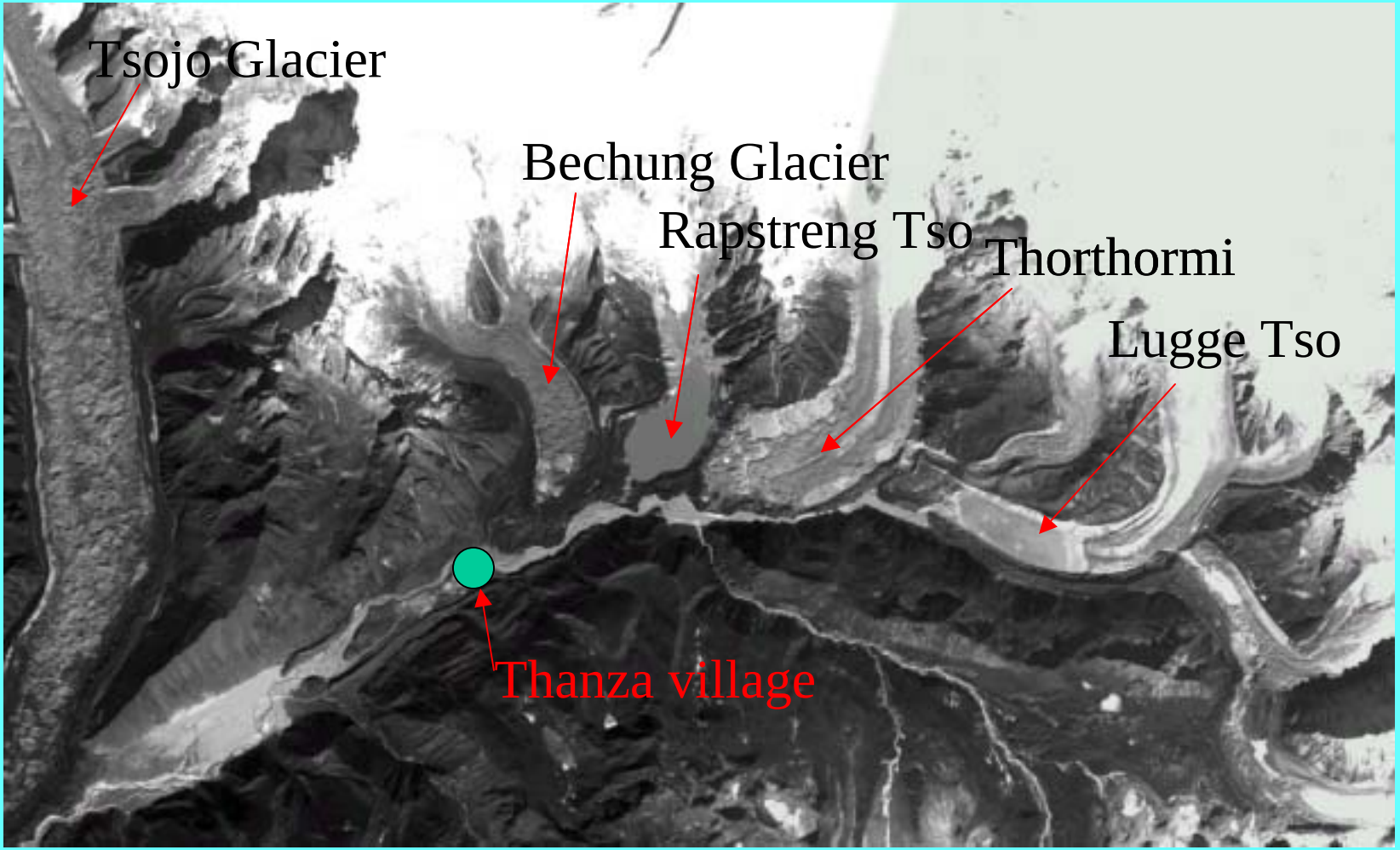
Summary of lakes in the Upe region

- 1999-Expedition to Chubda Tsho in the Head Waters of Chamkhar Chhu, Bumthang.
- 1999-2001- Joint Bhutan-Austria Project for risk assessment of glaciers & glacial lake

METHODS OF MONITORING

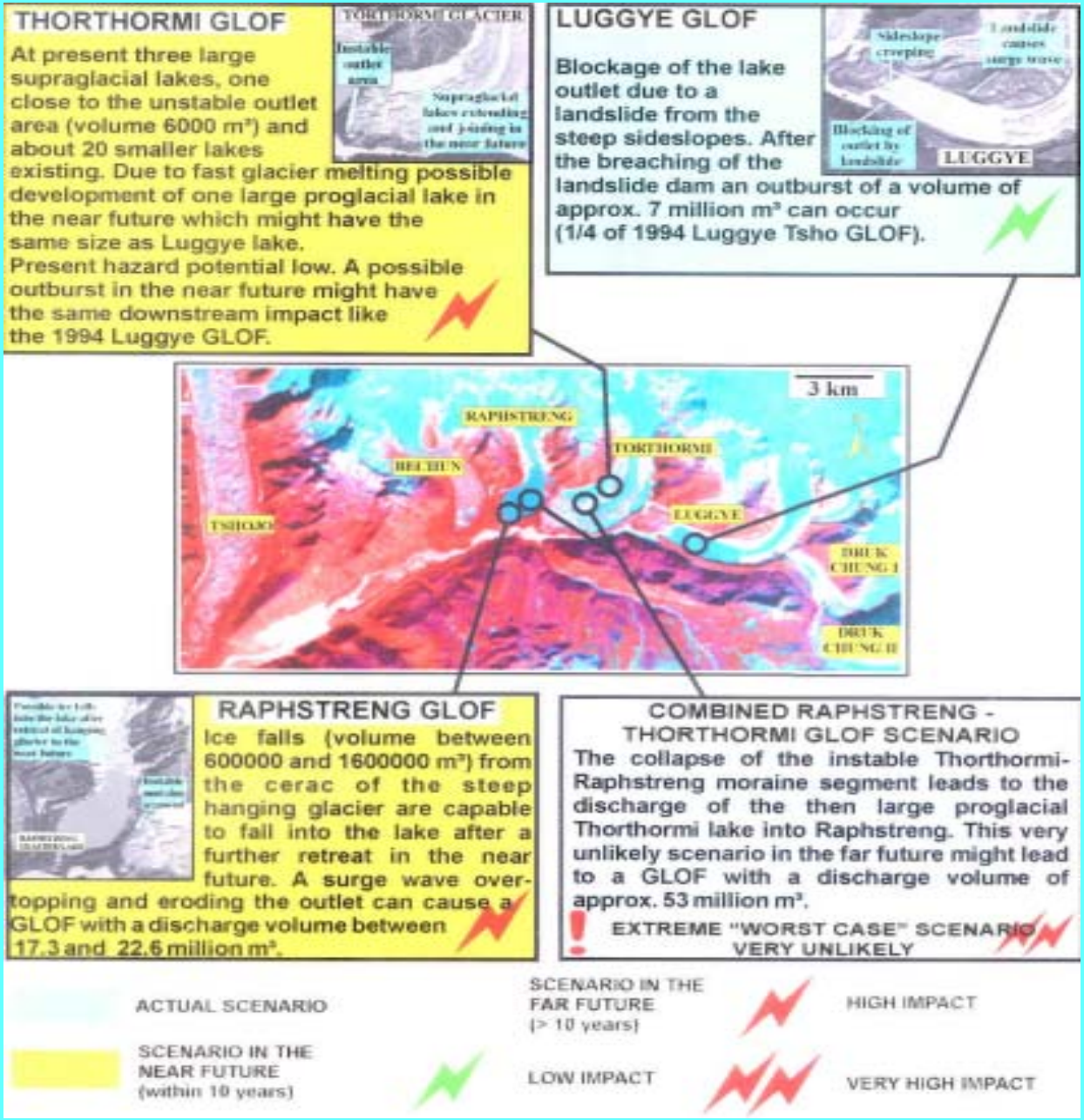
- Time series digital and hardcopy maps and satellite images: to show development and change of glacial lakes in past. Use of DEM.
- Compile results of time series analysis and other data layers.
- Compile all necessary tabular data, maps and charts of those glacial lakes: changed in size or of potential risk

Present Scenario

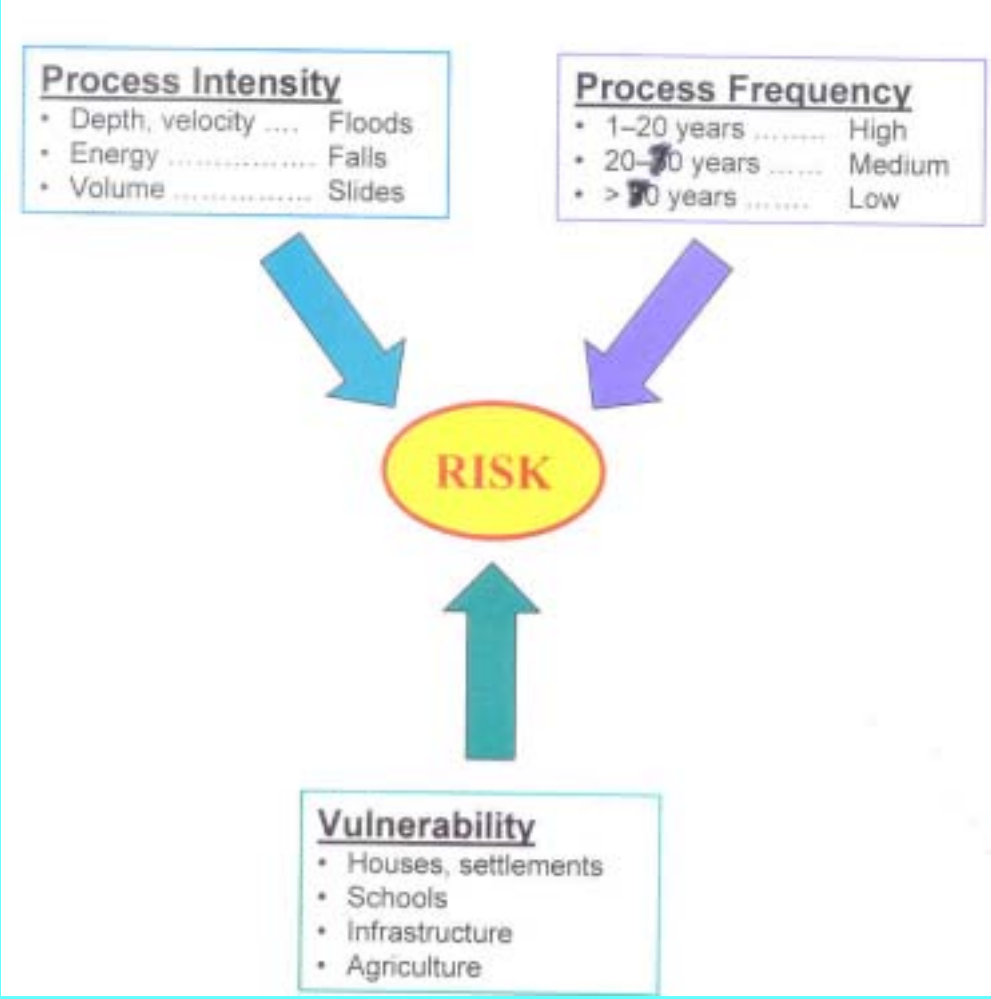


IRS1D PAN 3 January 1999

Possible GLOF scenario in Lunana



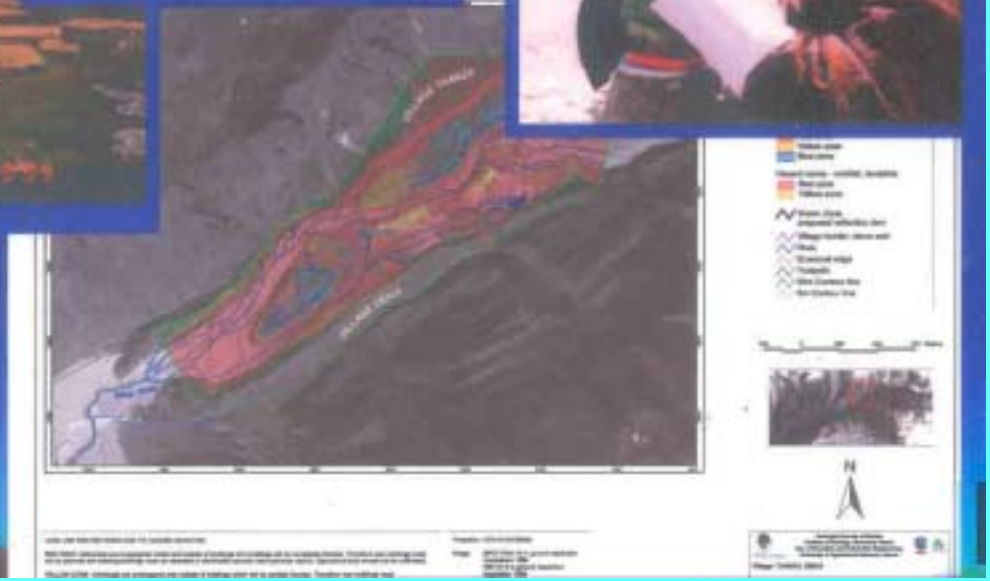
Proposed Risk assessment concept



Risk Assessment: Geo-Hazards

Geo-hazards:

- Rock-fall
- Land slide
- Flash flood



Hazard Zonation Concept

	Individual Risk	Common Risk
Red "Prohibition zone"	Generally: Individuals are endangered inside and outside of buildings. Heavy processes having a high recurrence probability.	Generally: Buildings are completely destroyed. Only water floods: When buildings are completely flooded up to the roof or people cannot escape onto the roof.
Yellow "Regulation zone"	Generally: Individuals are endangered only outside of buildings. Heavy processes having low to medium recurrence probability. Gradual processes having medium to high recurrence probability.	Generally: Buildings can be partly damaged.
Blue "Regulation zone"	Generally: People are only slightly endangered outside buildings. Processes, which do not have high or medium recurrence probability.	Generally: Damages to buildings are not probable. Processes don't have high recurrence probability.
Brown "Information zone"	Areas, which are reserved for technical mitigation measures or for bio-engineering measures later on.	

Hazard Assessment of Lunana glacial lakes

	GLACIER	MORAINES	OUTLET	ASSESSED ACTUAL HAZARD POTENTIAL	ASSESSED HAZARD POTENTIAL IN THE NEAR FUTURE (10 years)	PROPOSED MITIGATION MEASURES
TSHOJO GLACIER	Decaying snout. Slumped subglacial caves indicate subglacial water surges.	Minor slides on the inner side of the TM, but no signs of major instabilities.	Stable. No potential for blocking by landslides.	NO	Possible risk evolving depending on glacier decay and formation of supraglacial or proglacial lake(s).	Regular inspections on a yearly basis.
BECHUN GLACIER AND SUPRA-GLACIAL LAKES	Glacier snout shows strong melting and decaying. Supra-glacial lakes developed.	Minor slides on the inner side of the RLM, but no sign of major instabilities.	Present outlet stable. After further glacier decay outlet development at LLM possible.	NO	Possible risk evolving depending on glacier decay and formation of second outlet.	Regular inspections on a yearly basis.
RAPHSTRENG GLACIER	Glacier in receding to stagnant position (2000). Large proglacial lake developed.	TM and RLM stable. LLM (RAPH/THORT segment) shows slides and probably contains ice lenses.	Outlet after Indo-Bhutanese mitigation measures stable.	NO	After a further retreat of the steep hanging glacier ice falls (600000 to 1600000 m³) causing a surge wave, eroding and overtopping the outlet, can cause a GLOF (17-22 mill. m³).	Monitoring program and regular inspections on a yearly basis.
THORTHORMI GLACIER AND SUPRA-GLACIAL LAKES	Fast decaying glacier snout. Supraglacial lakes expanding. Possible formation of large proglacial lake.	RLM stable. TM destabilised by seepages. LLM (Thorthormi – Raphstreng segment) shows sliding and is probably destabilised by melting ice lenses.	Steep active channel with landslides not capable to block the channel. Seepages in the right sideslope. Possible reactivation of second outlet.	Outburst of small supraglacial lake (6000 m³) is possible. No major impact on the downstream area.	Channel back cutting can result in liquefaction and erosion of the channel bottom because of seeps triggering dam piping. After formation of proglacial lake (approx. size like Luggye lake) potential of a GLOF comparable to the 1994 Luggye event.	Monitoring program. In case of fast development of proglacial lake technical mitigation measures in outlet. Hazard zonation plans, EWS.

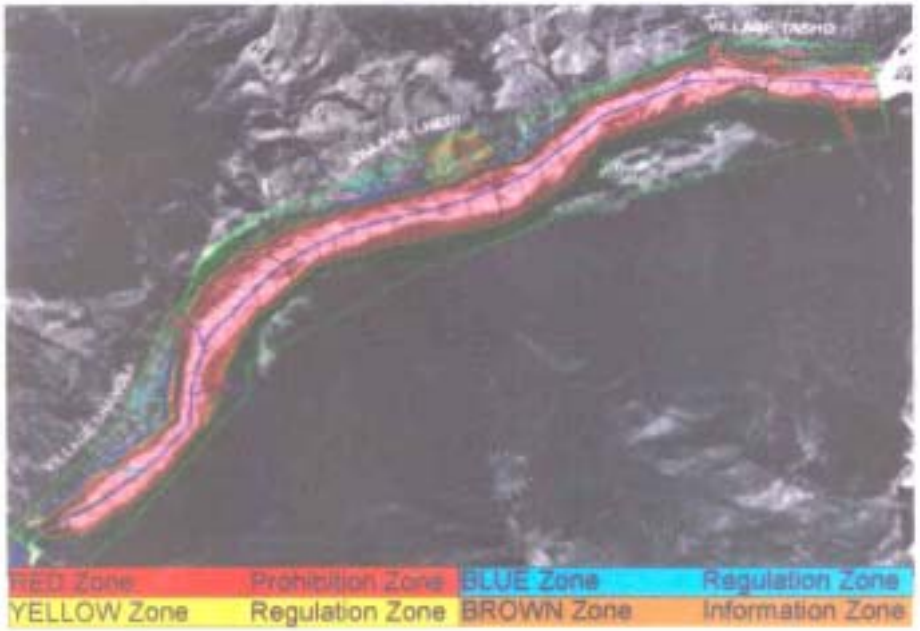
NO HAZARD POTENTIAL

LOW HAZARD POTENTIAL

MEDIUM HAZARD POTENTIAL

HIGH HAZARD POTENTIAL

Hazard Zonation Plan



NECESSARY ACTIONS

Tasho

- Securing of two houses by gabion reflection dam presently located in the yellow zone (endangered by backwater effects).
- Construction of a gabion or reflection earth dams with a height of 3 m.

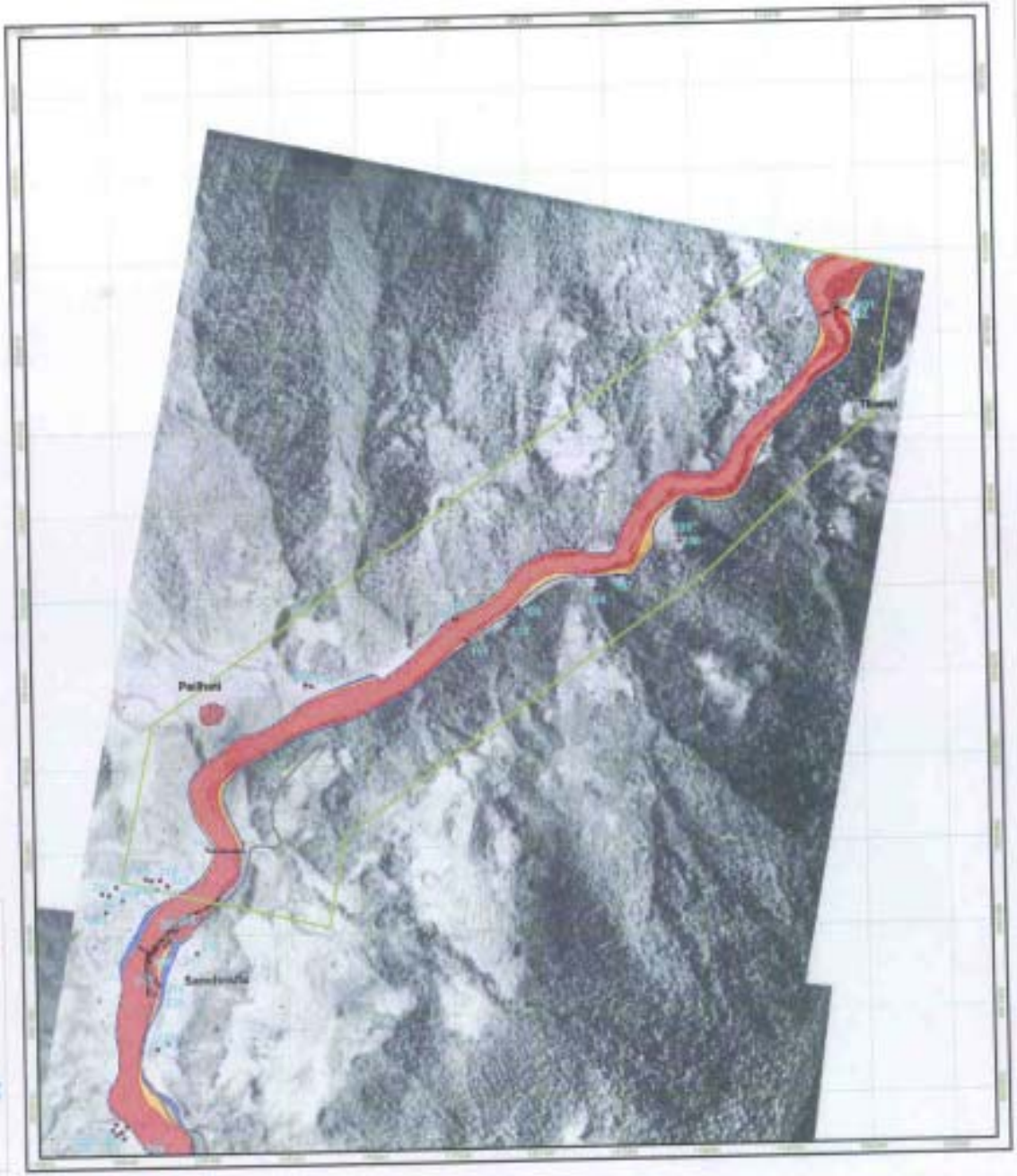
Lhedi

- Village not endangered due to water / sediment flood.
- No new building to be constucted in the yellow zone endangered by rock fall.
- Reflection walls can be constructed to reduce rock fall impact.

Shangsa

- Securing of one house by a gabion reflection dam (endangered by backwater effects).
- Construction of a gabion or reflection earth dams with a height of 3 m.

Securing by gabion dam



HAZARD ZONATION PLAN 1

Hazard zonation border

Houses, Huts
- House
- Chorten

Settlement
Building

Hazard Zones
for water/sediment floods only
- Red zone
- Yellow zone
- Blue zone

Infrastructure
- Road
- Bridge
- Dam
- Pipeline

Proposed measures
- Embankment Dam
- Wood Retention Structure

N

THIMJI School - SAMDRINKHA Suspension Bridge

Dzongkag PUNAKHA

Outburst Flood Mitigation
Project 2002-2003
Pro Chhu, Bhutan

HAZARD ZONATION PLAN
THIMJI - SAMDRINKHA

Scale 1: 12,500

Map 1

HAZARD ZONATION PLAN 2

Hazard zonation border

Houses, Huts
- House
- Chorten

Settlement
Building

Hazard Zones
for water/sediment floods only
- Red zone
- Yellow zone
- Blue zone

Infrastructure
- Road
- Bridge
- Dam
- Pipeline

Proposed measures
- Embankment Dam
- Wood Retention Structure

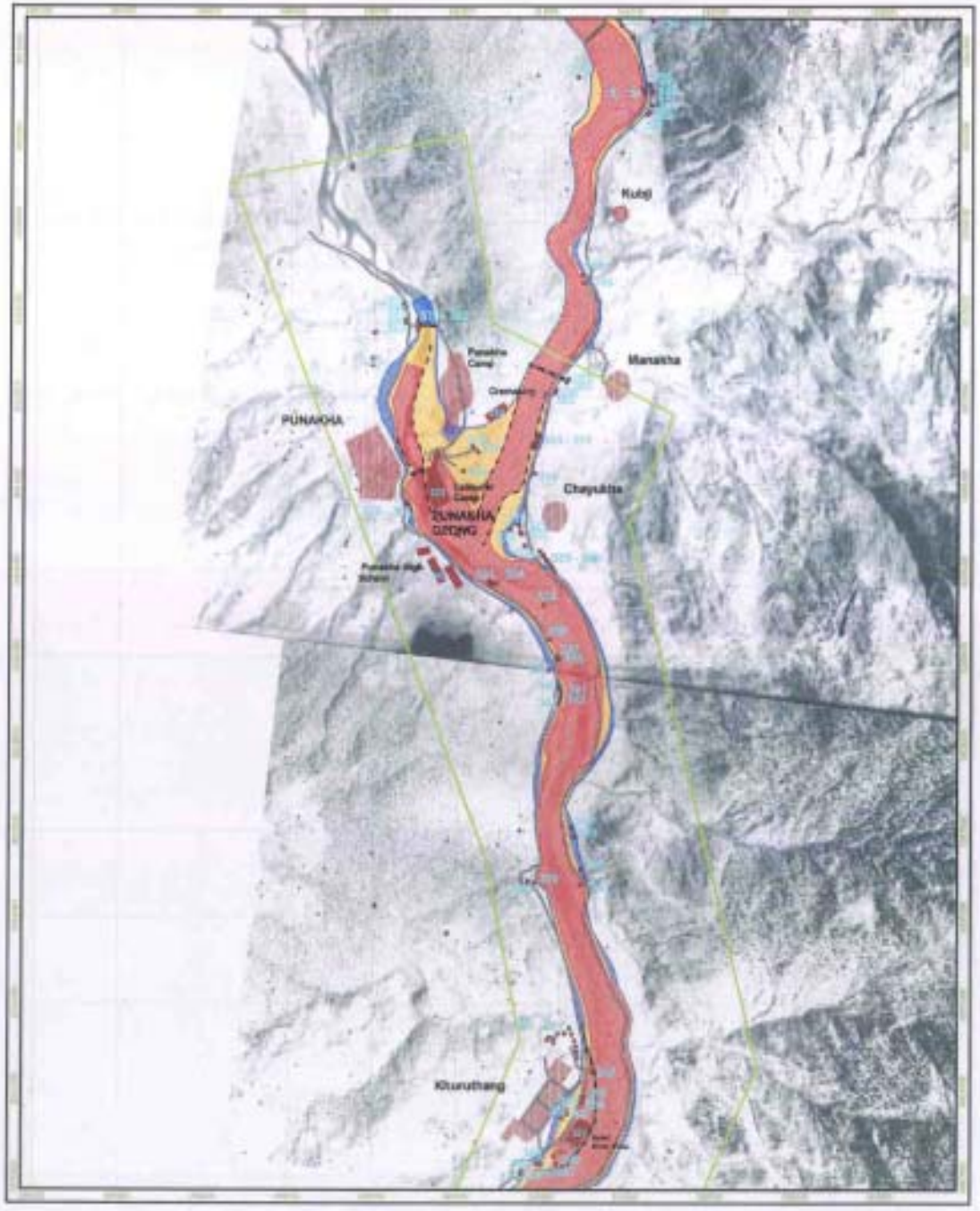
N

SAMDINGKHA Village - MANAKHA Village

Outburst Flood Mitigation
Project 2002-2003
Pho Chhu, Bhutan

HAZARD ZONATION PLAN
SAMDINGKHA - MANAKHA

Scale 1: 10,000



HAZARD ZONATION PLAN 3

Hazard zonation border

Houses, Huts
- House
- Chorten
- Settlement
- Building

Hazard Zones
for water/sediment floods only
- Red zone
- Yellow zone
- Blue zone

Infrastructure
- Road
- Bridge
- Dam
- Pipeline

Proposed measures
- Embankment Dam
- Wood Retention Structure

N

PUNAKHA Suspension bridge - KHURUTHANG Village

Dzongkag: PUNAKHA

Outburst Flood Mitigation
Project 2002-2003
Pho Chhu, Bhutan

HAZARD ZONATION PLAN
PUNAKHA - KHURUTHANG

Scale 1: 12.000

Map 3

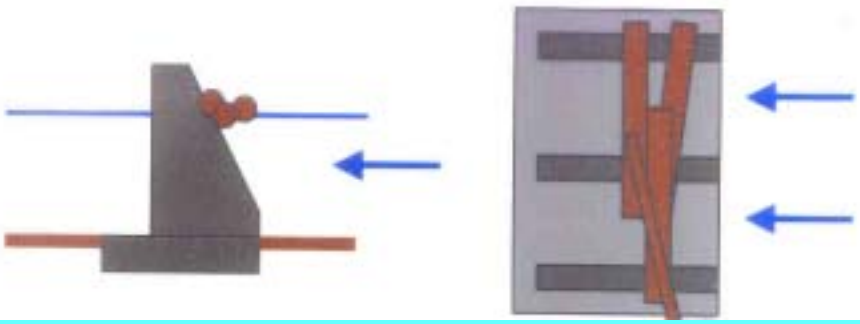
Recommendations-Technical mitigation measures

Lunana

- Thorthomi Tsho Spillway stabilization
- Dams 3-5m (Thanza, Demji, Tshojo, Lhedi)
- Footpath shift (Lhedi-Tasho, Thorthomi-Tshojo)
- Heli pads + emergency provision

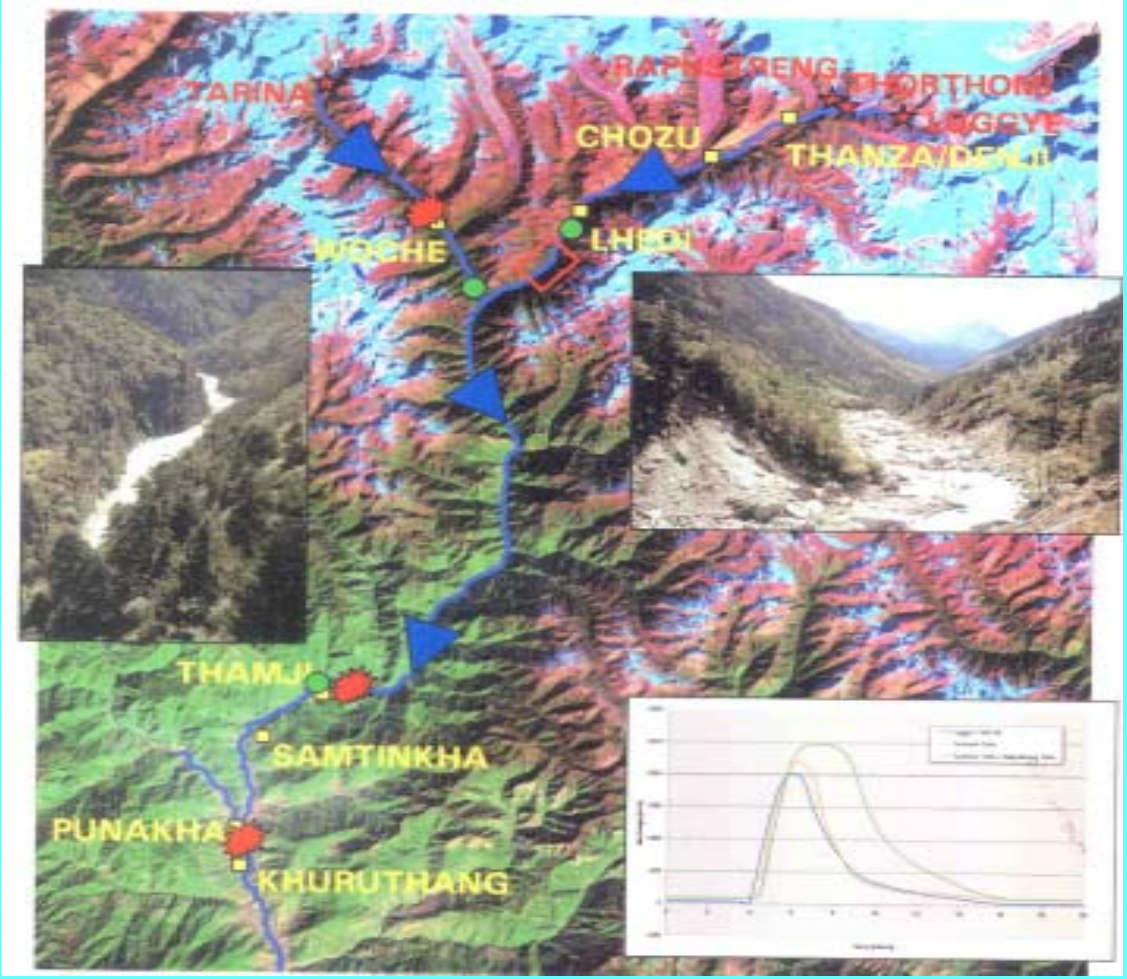
Tamji School – Khuruthang

- Embankment + deflection dams (Samtinka, Thamji school, Khuruthang, Mo/Pho Chhu Junction)
- Bridges (Samtinka, Khuruthang)
- Roads (Khuruthang-Punakha, Wangdue-Samtinka)
- Retention dam 10-15% reduction at peak flow
- Woody debris retention (Laboratory tests needed)



Risk Management

Flood Routing along Pho Chu



Technical GLOF early warning system

Conclusions

- Hazard Potential of worst case outburst scenarios
- Low hazard potential for Tarina lakes
- Near future risk of Rapstreng Tso (Ice fall)
- Far future : Thorthormi/Rapstreng outburst (53 million m3)

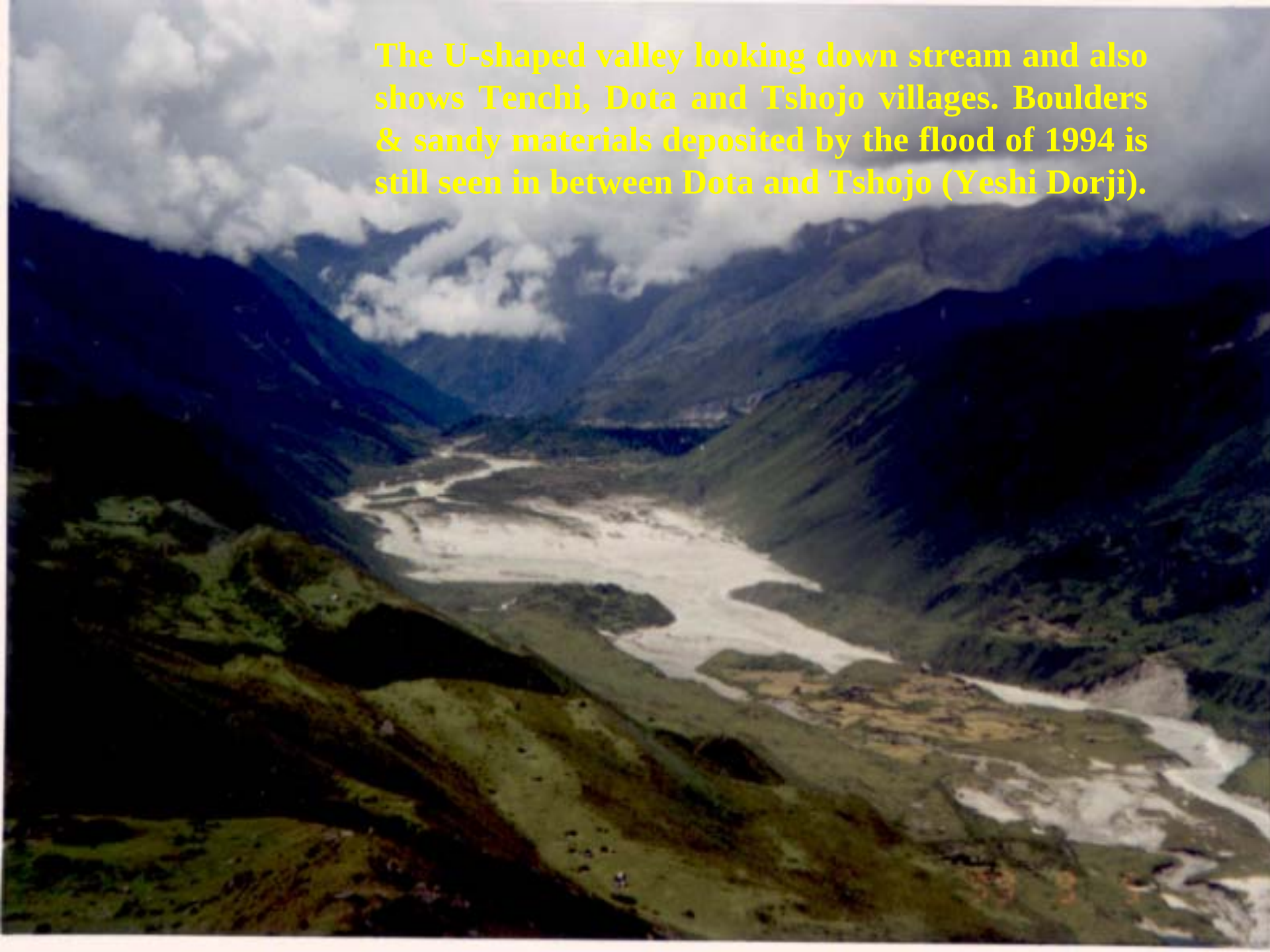
- build national institutional capacity to assess and monitor GLOF phenomena
- disseminate to responsible organisations in the region
- Strengthened capacities of national institutions.

1994 GLOF & ITS EFFECTS

- Loss of lives – human, cattle
- Damages to Properties – Dzong, bridges, houses, land

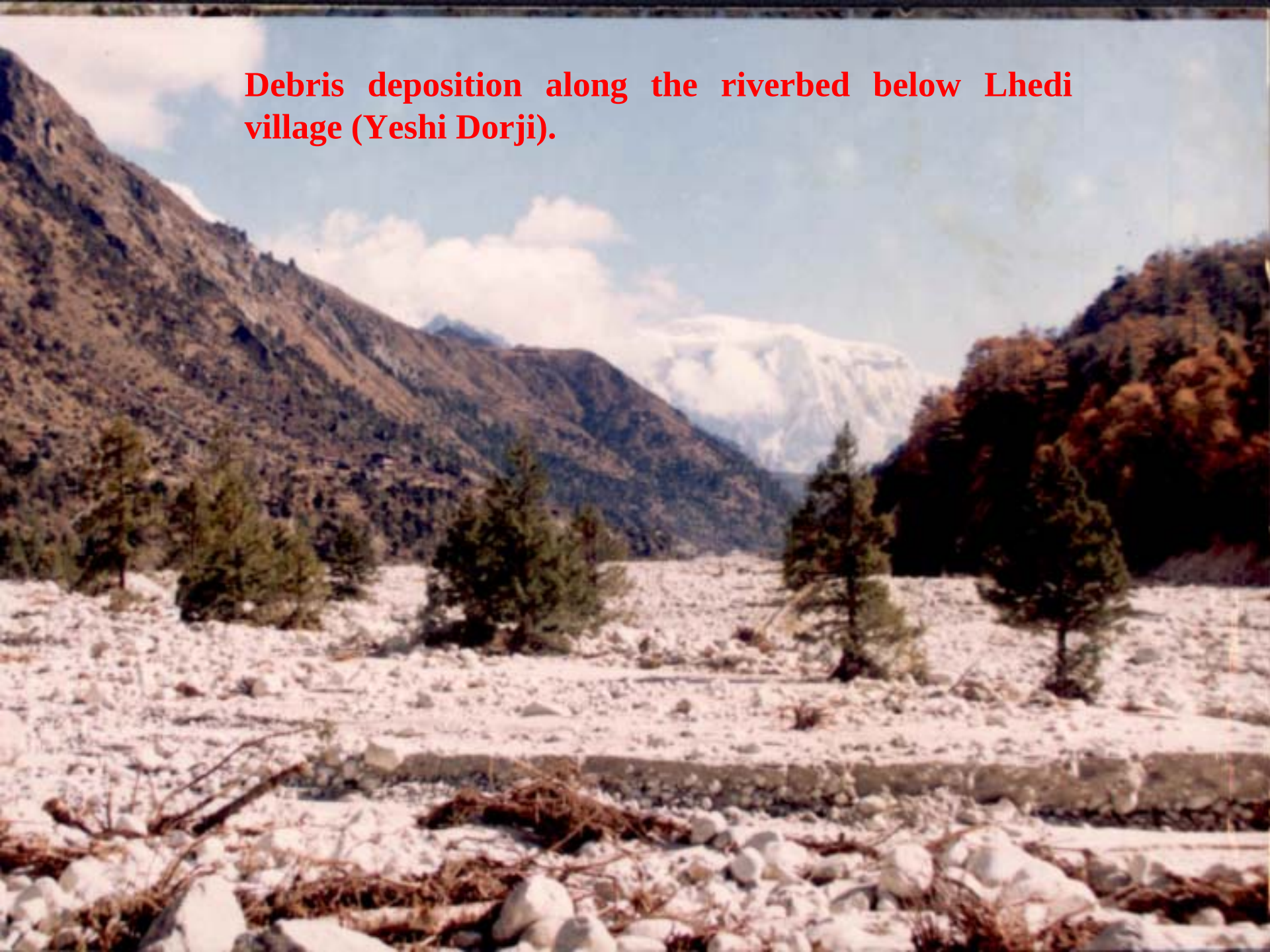
The supraglacial lakes being formed on Thorthormi Glacier and erosion caused by the 1994 flood on the left lateral moraine (Phuntso Norbu, October, 1994).

Punakha Dzong after 1994 GLOF from Luggi Tsho. It shows the confluence of Pho Chu and Mo Chu below the Dzong and the scars of the back flow water after it had joined Mo Chu and dammed the flow above the Dzong (Photo source: Mr. Phuntso Norbu, 1994 three days after the GLOF)

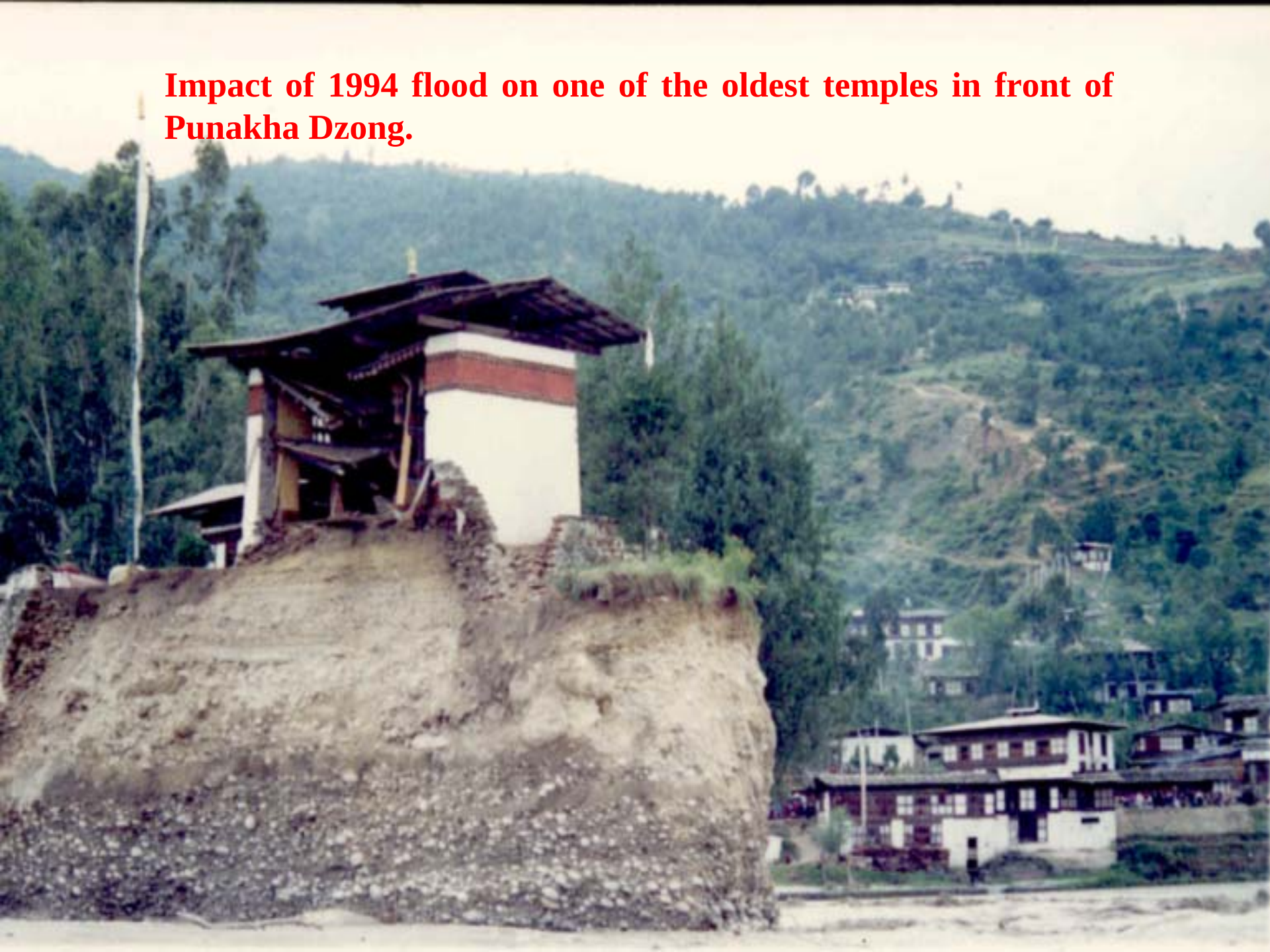


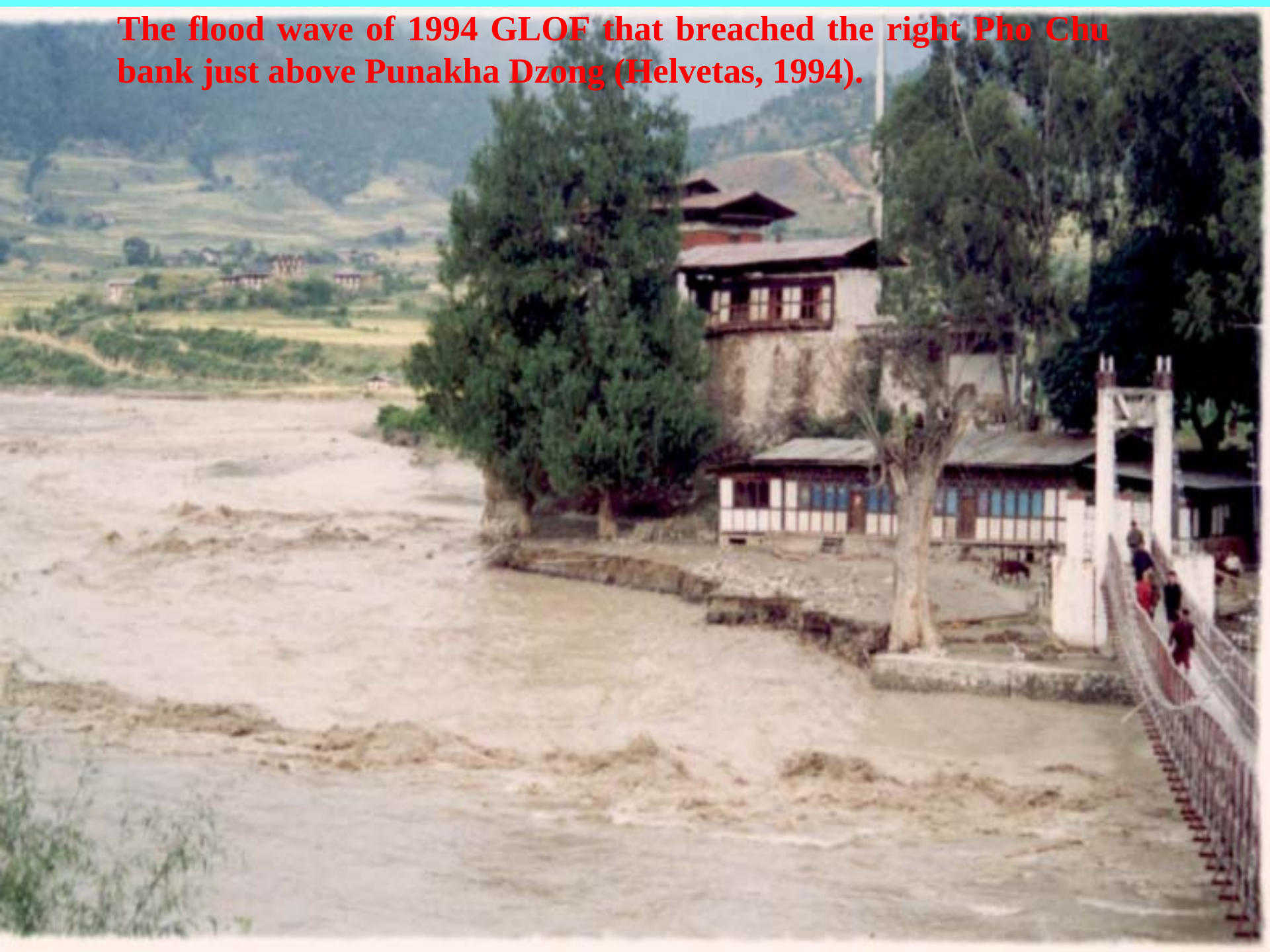
The U-shaped valley looking down stream and also shows Tenchi, Dota and Tshojo villages. Boulders & sandy materials deposited by the flood of 1994 is still seen in between Dota and Tshojo (Yeshi Dorji).

Thanza village & remnants of 1994 flood downstream (Tshering Tashi, NEC).

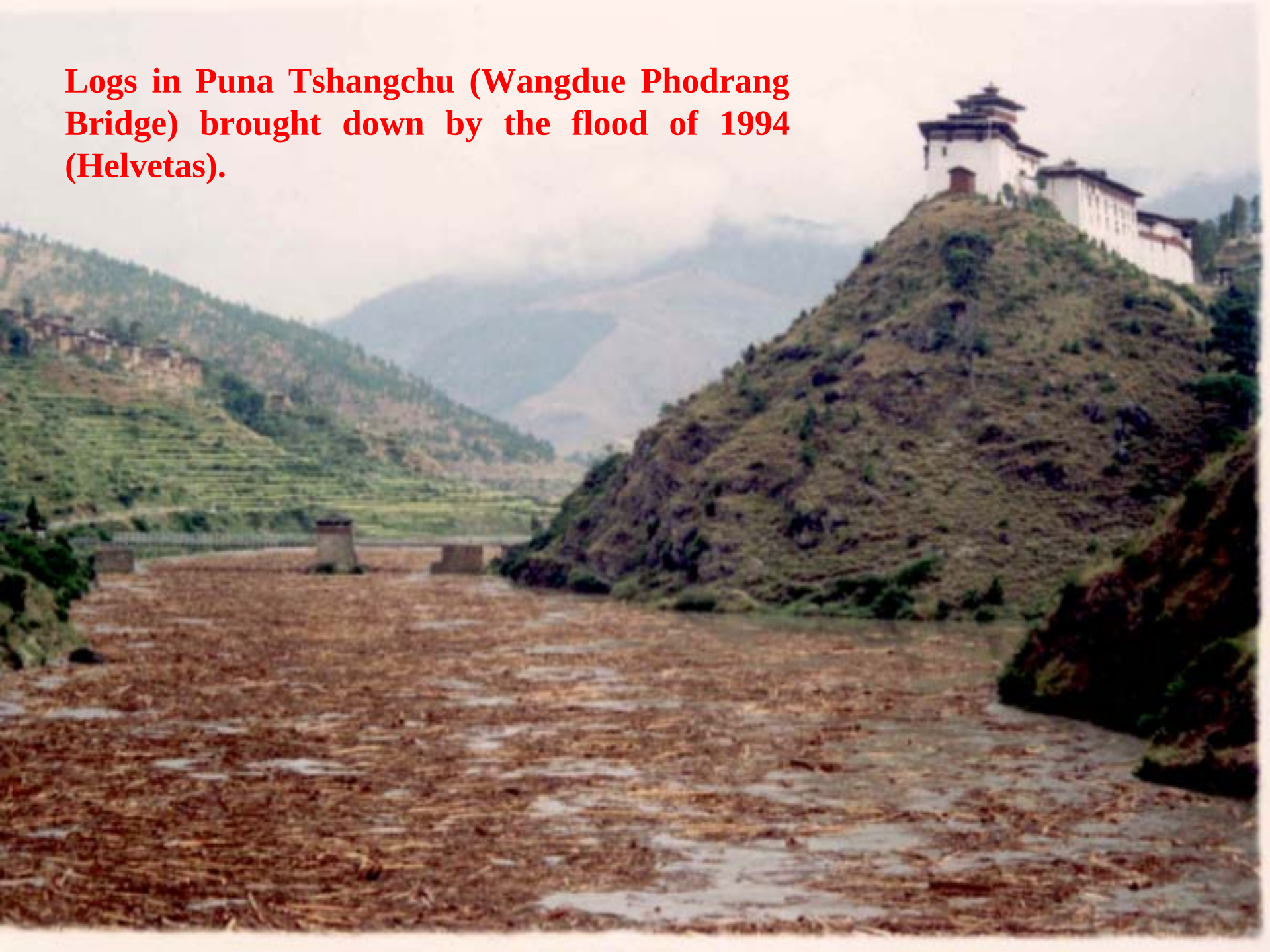


Debris deposition along the riverbed below Lhedi village (Yeshi Dorji).

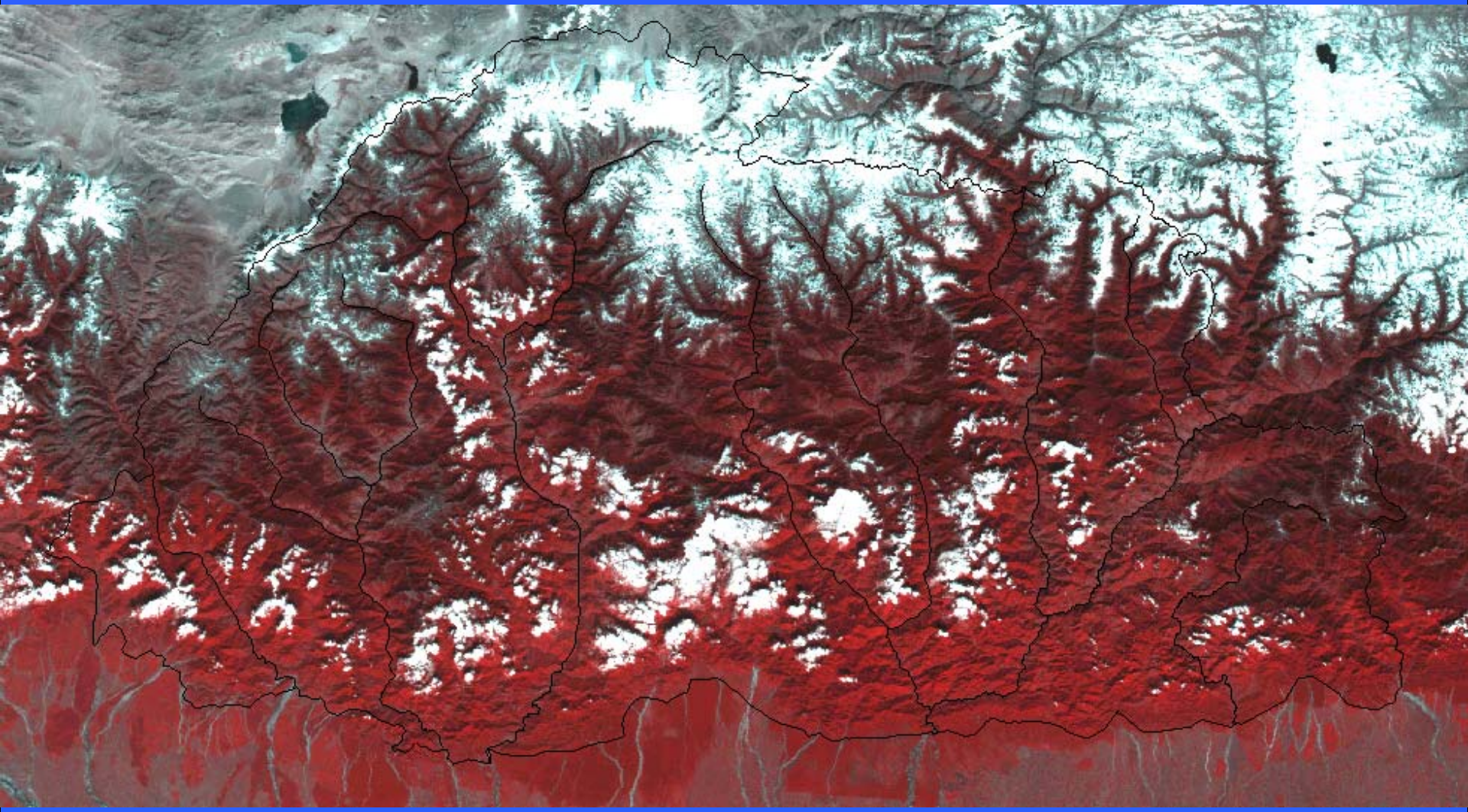

Impact of 1994 flood on one of the oldest temples in front of Punakha Dzong.



The flood wave of 1994 GLOF that breached the right Pho Chu bank just above Punakha Dzong (Helvetas, 1994).



Logs in Puna Tshangchu (Wangdue Phodrang Bridge) brought down by the flood of 1994 (Helvetas).

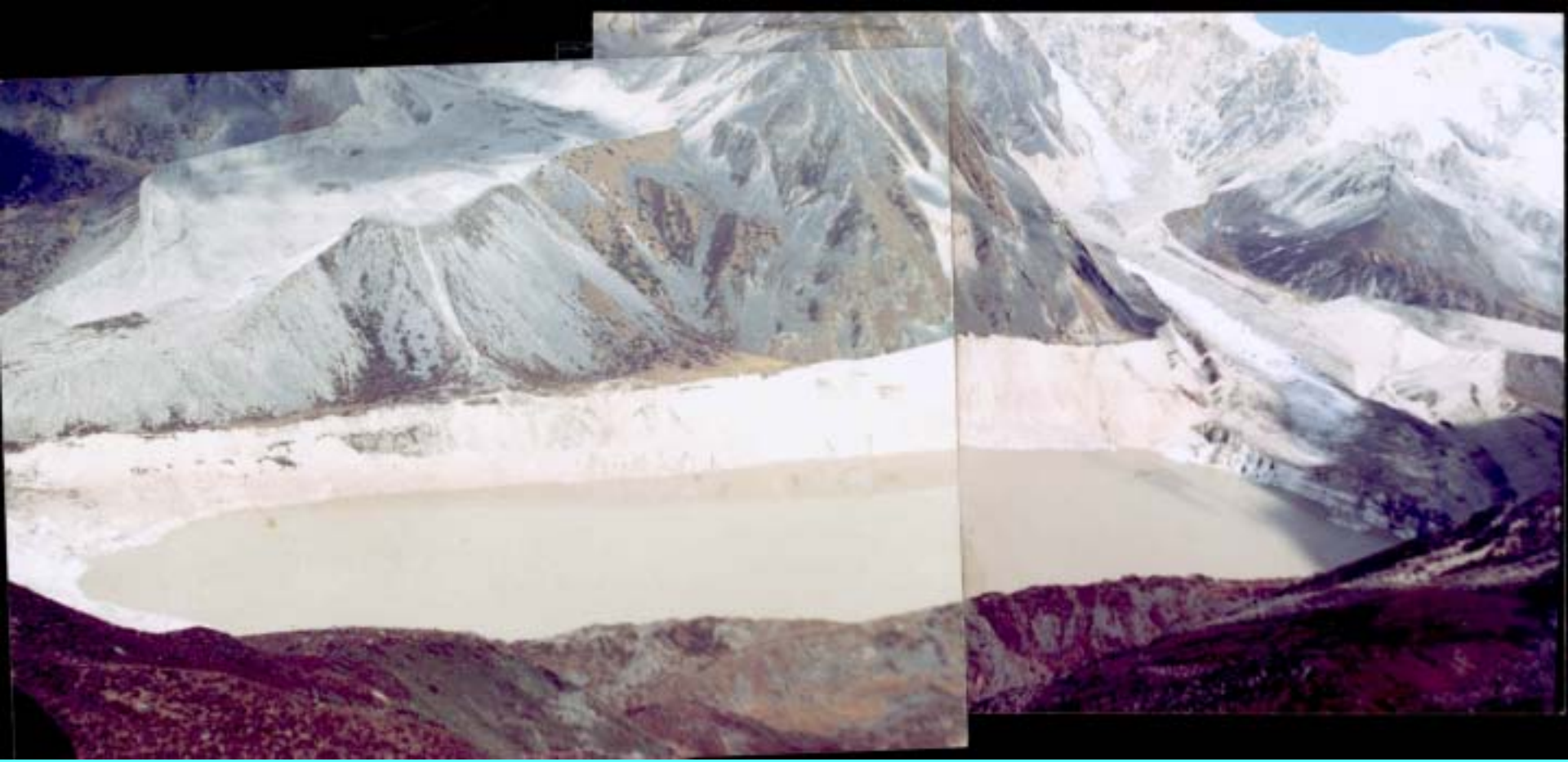


Land above 4200 masl is about 20.5% of Bhutan

Glaciers area about 3.3% of Bhutan

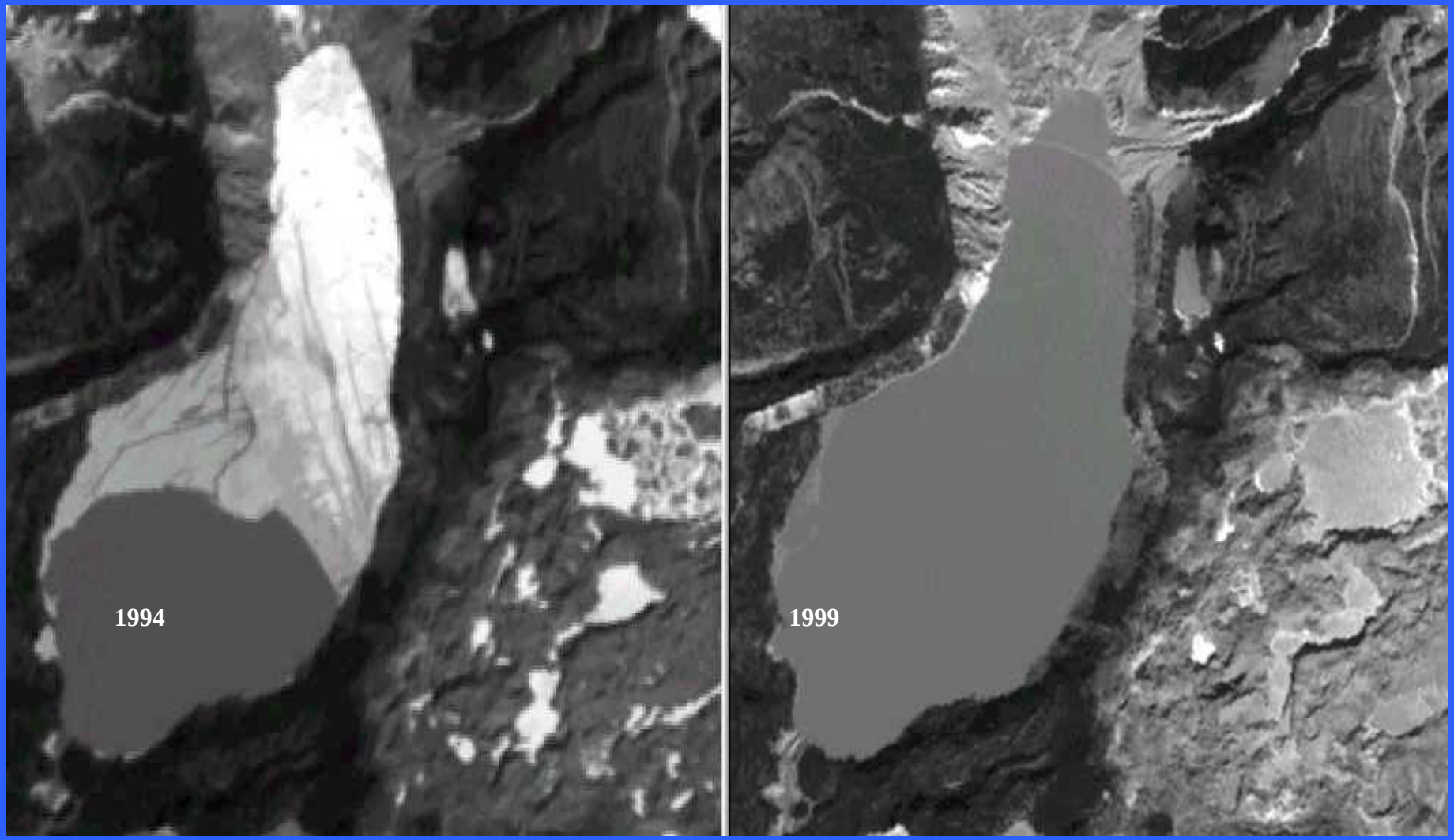
Luggi Tsho Lake which burst out in 1994 October 7

(Photo source: Phuntso Norbu, October 1994)



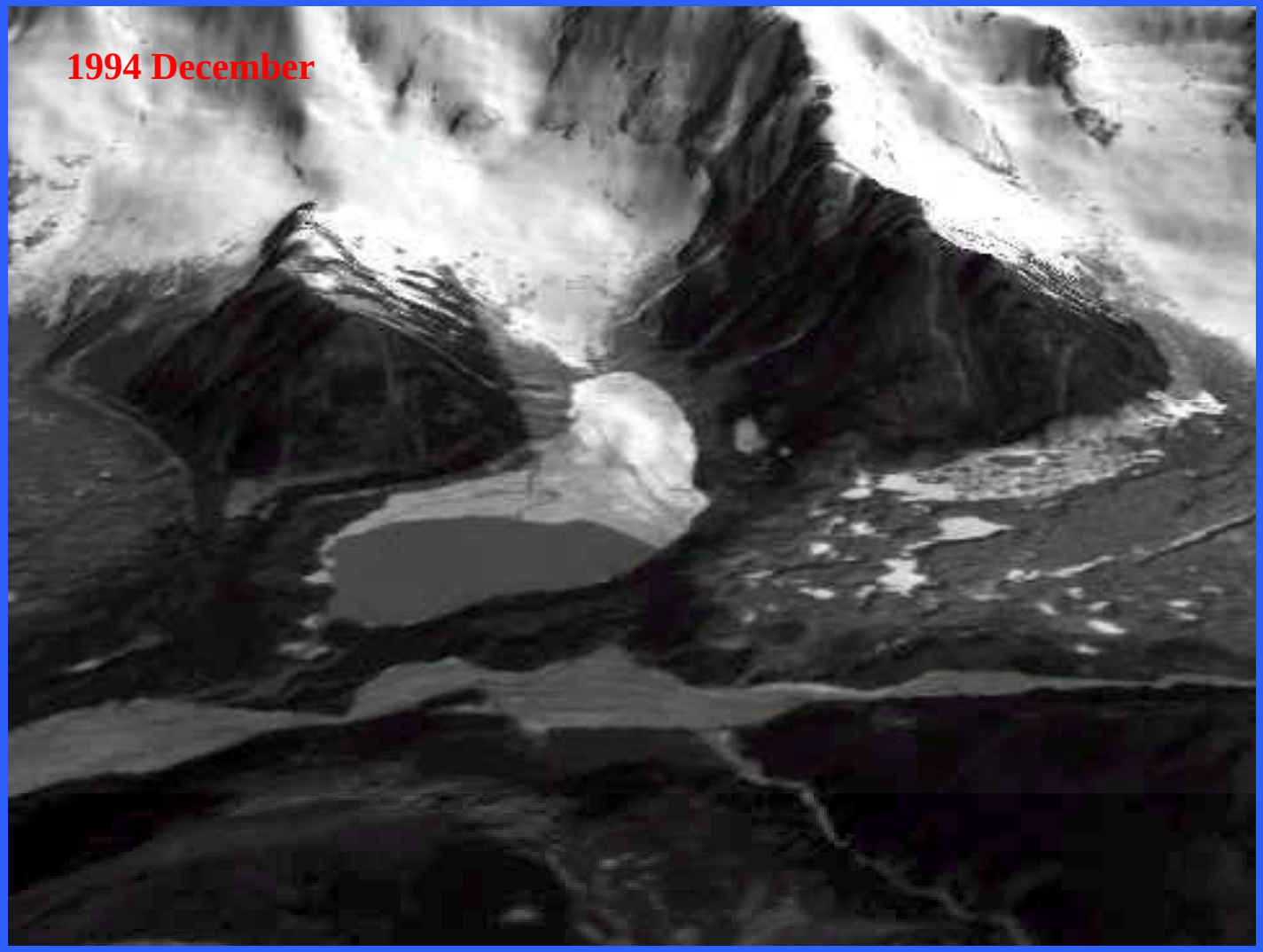
Luggi Tsho glacial lake two weeks after the flood of 7 October 1994. (Photo source:Yeshi Dorji).

Raphsteng Lake and glacier tongue of Thorthormi glacier - Bhutan

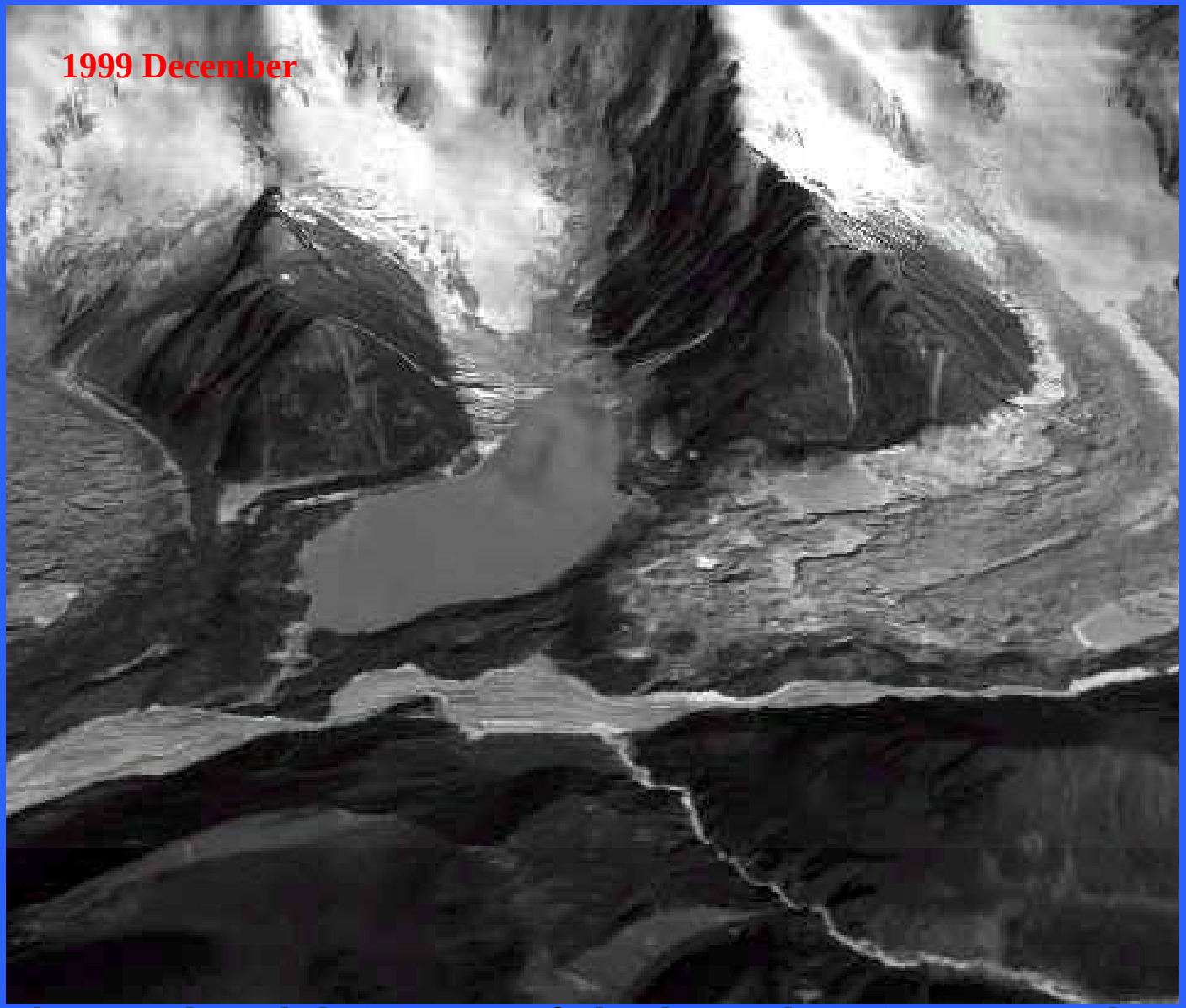


1994 December 25

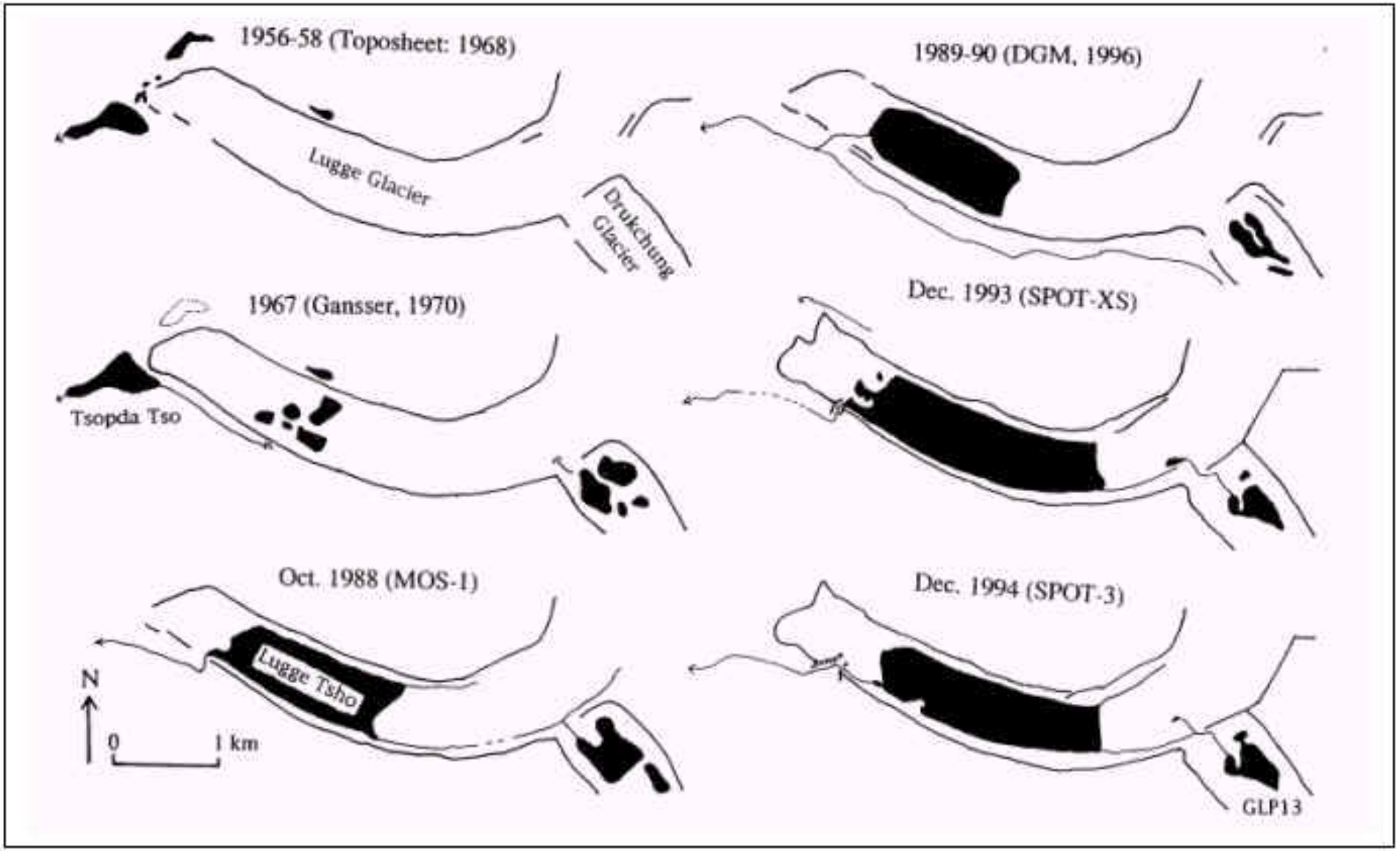
1999 January 3



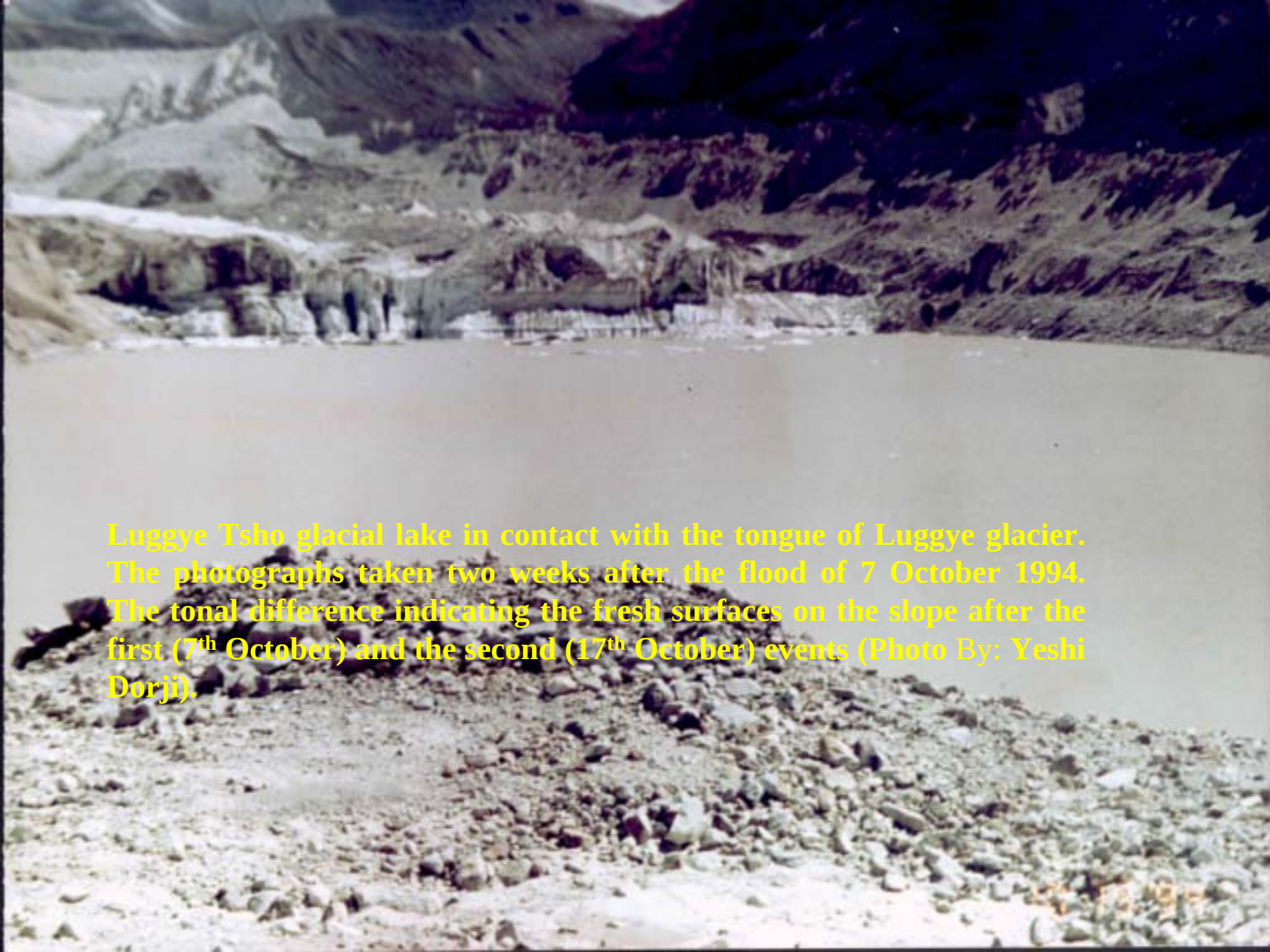
Raphsteng Lake and glacier tongue of Thorthormi glacier in 1994 December 25 (SPOT PAN) and in 1999 January 3 (IRS1C PAN). Both the images area drapped over the DEM generated from topographic map of 1:50,000 scale.



Raphsteng Lake and glacier tongue of Thorthormi glacier in 1994 December 25 (SPOT PAN) and in 1999 January 3 (IRS1C PAN). Both the images area drapped over the DEM generated from topographic map of 1:50,000 scale.



Expansion of Lugge Tsho, Tsopda Tsho and Drukchung Tsho from 1956 to 1994 (Ageta et al., 1999)



Luggye Tsho glacial lake in contact with the tongue of Luggye glacier. The photographs taken two weeks after the flood of 7 October 1994. The tonal difference indicating the fresh surfaces on the slope after the first (7th October) and the second (17th October) events (Photo By: Yeshi Dorji).

Within Luggye Tsho - the occurrence of dead ice within the moraine (Photo By: D. R. Gurung, 1999).

End moraine of Luggye glacier showing slumps and fine sand indicating that it is being underlain by dead ice (D. R. Gurung1999)

The Raphstreng Tsho, right lateral moraine, glacial snout, the new excavated outlet and erosion caused by the flood of 1994 along the main river bed (Phuntsho Norbu, 1999).


3 10'00

THANK YOU & TASHI DELEK