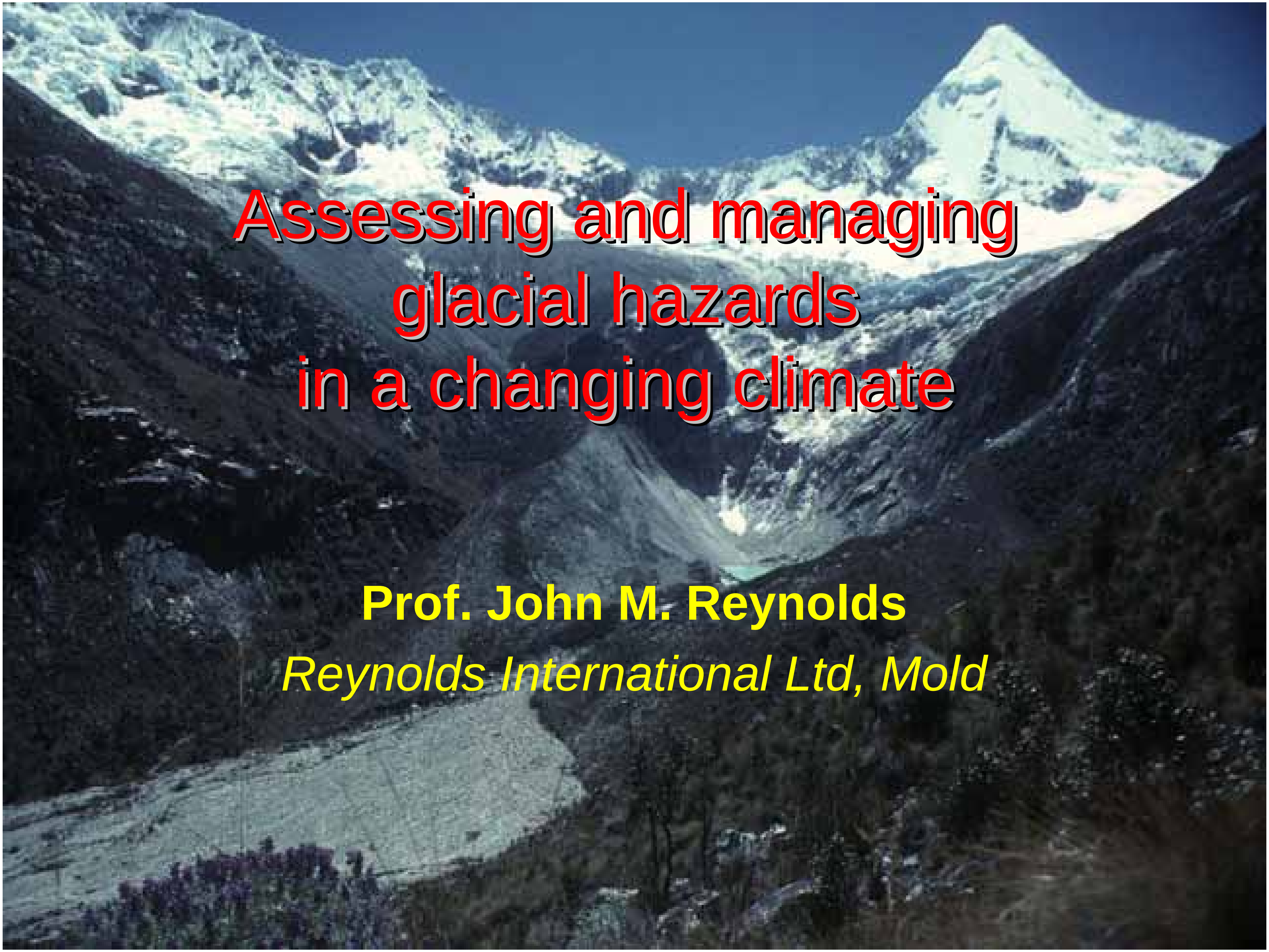


Assessing and managing glacial hazards in a changing climate

Prof. John M. Reynolds

Reynolds International Ltd, Mold

Glacial hazards and climate change

As climate changes:

- The number of glacial lakes increases
- The volume of water stored in lakes increases

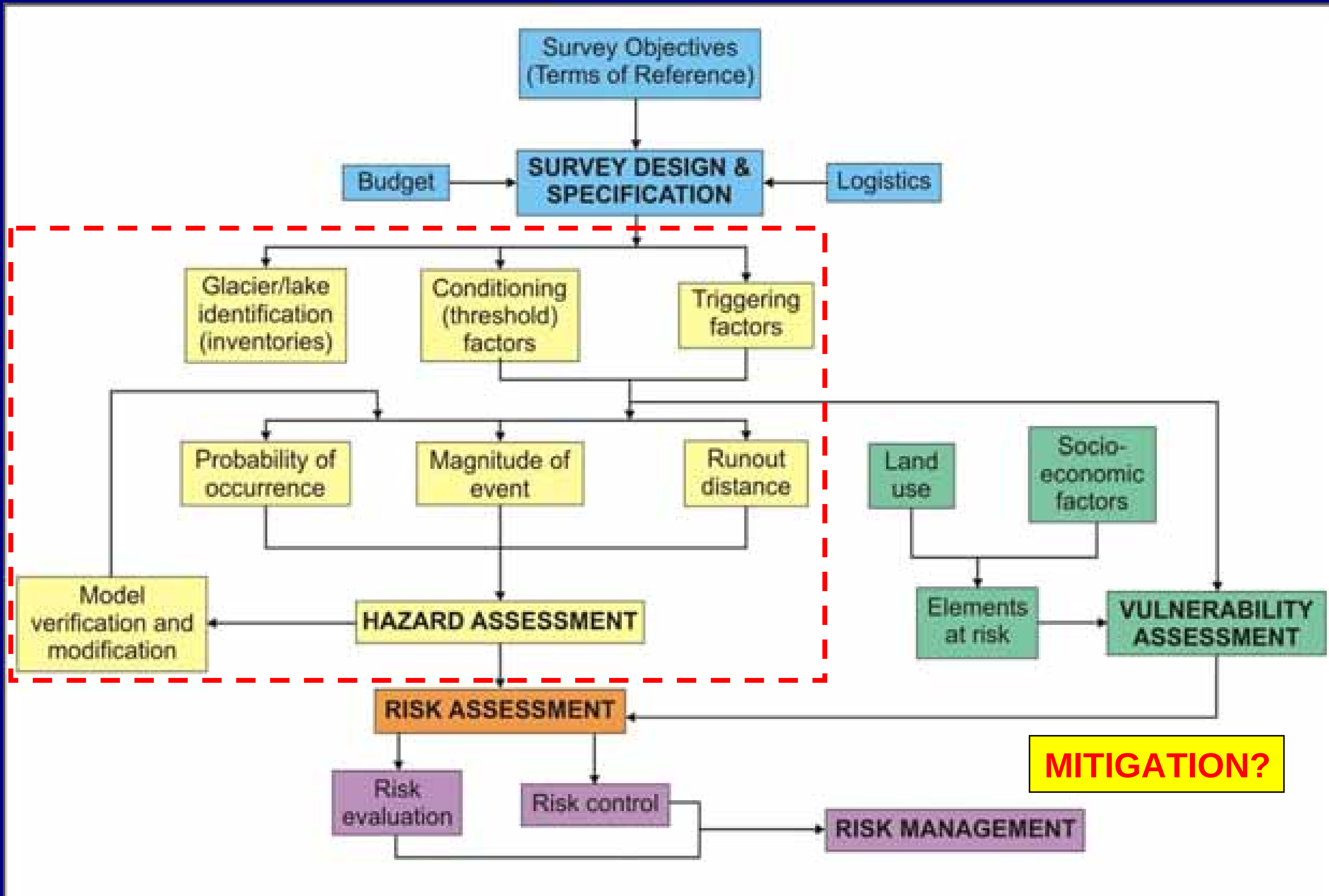
→ The **hazard increases**

Rural development is increasing into the high mountains:

- More roads, bridges
- Mining
- Hydropower
- Communities
- Tourist trails/lodges

→ The **vulnerability increases**

Example project structure for glacial risk assessment and management



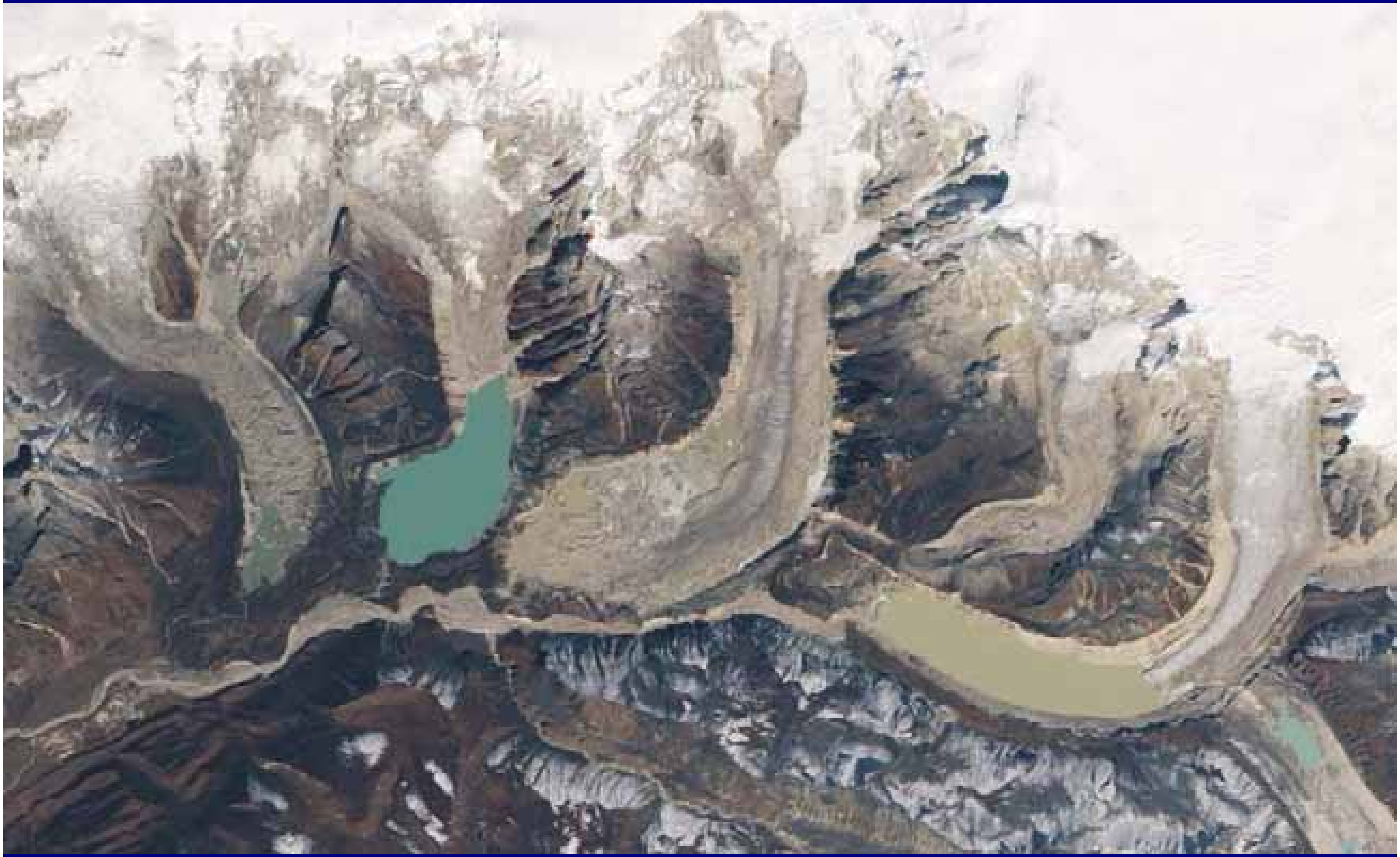
From *Guidelines for the management of glacial hazards and risks* (RGSL, 2003).

Remote sensing to characterise glacial hazards

Potential valley blockage and glacier dam

Bears Glacier, Tajikistan

Lunana lakes, northern Bhutan



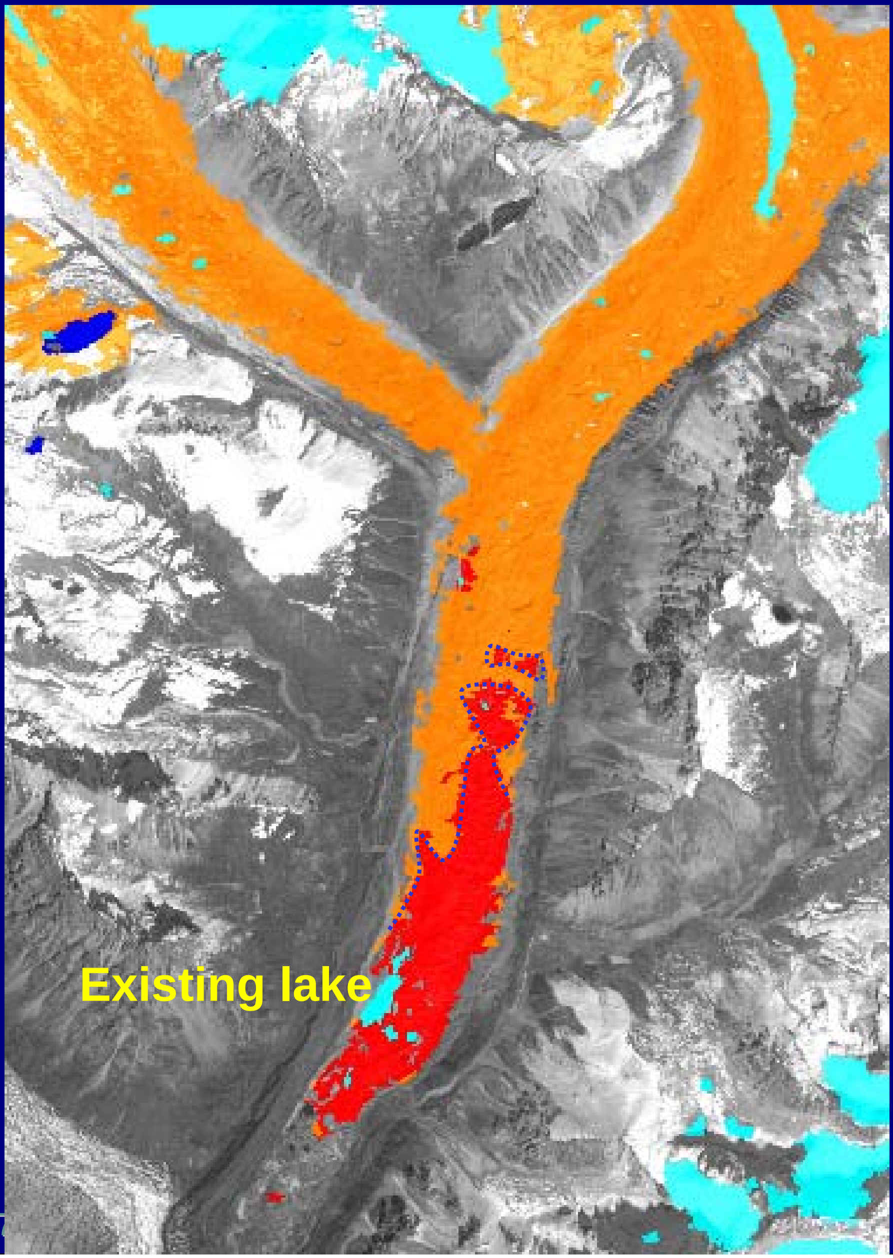
28th October 2009

Measuring glacier flow rates
using Synthetic Aperture Radar

Image courtesy of D. Quincey

Kangshung Glacier in Tibet (China)

Mapping existing lakes at risk and predicting where lakes might form



Defining areas of potential lake formation following the 2° Rule:

- Red < 2° - *new lake*
- Orange 2-6° - *ponds (transient)*
- Cyan >6° - *no ponds*

Repeat assessment after a gap of several years will reveal changes in actual and potential lake areas and indicate the rates of glacier surface deflation and increases in potential lake areas.

Reynolds (2000)

Negative mass balance
Stagnation of debris-covered ice tongue
Collapse of en-glacial drainage conduits
Behaviour dependent upon individual flow unit
Relative areas of accumulation zones to glacier flow unit size

Image courtesy of D. Quincey

Hazard assessment - factor analysis

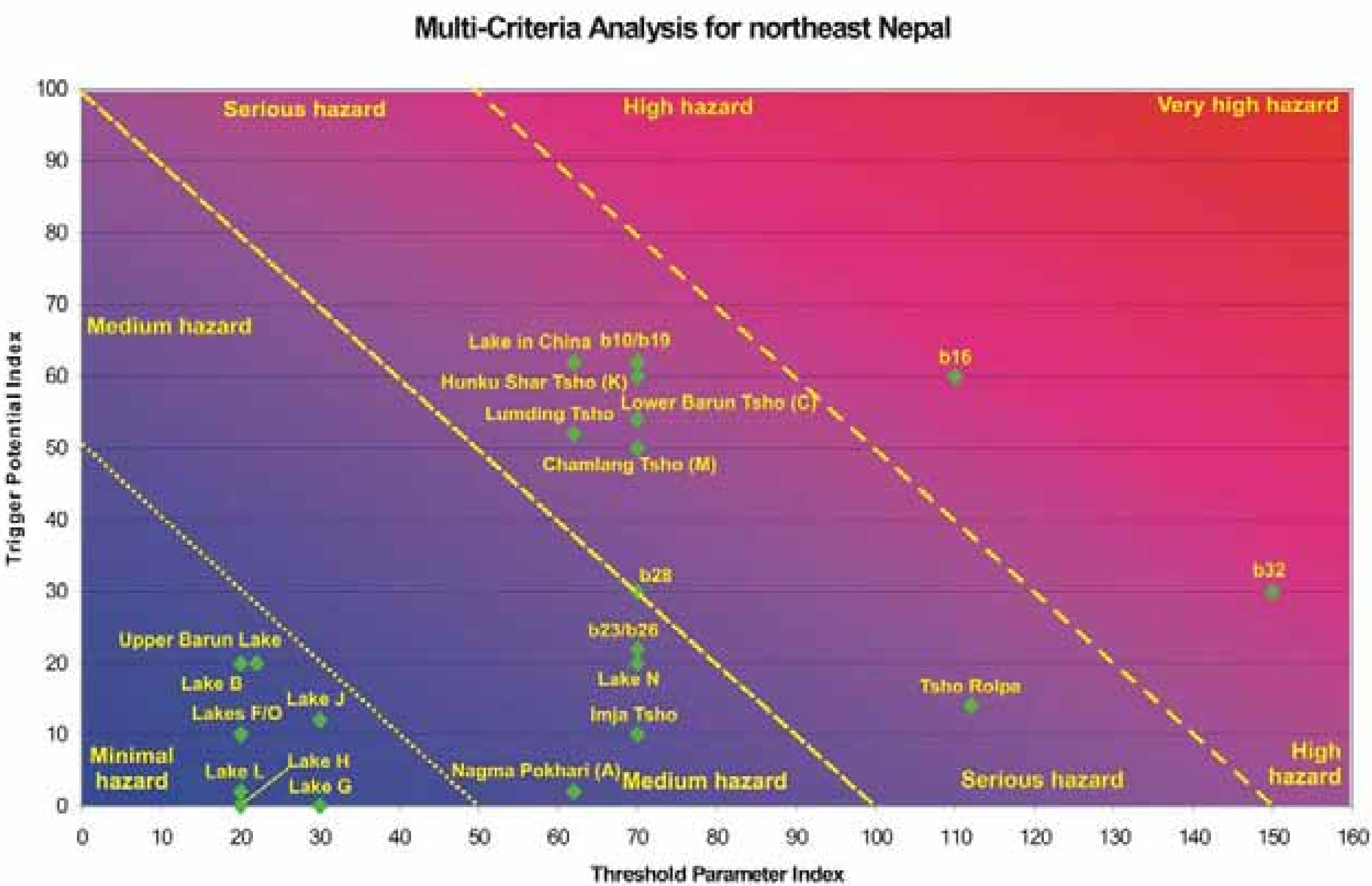
ID	Parameter affecting hazard\Score	0	2	10	50
1	*Volume of lake*	N/A	Low	Mod.	Large
2	*Lake level relative to freeboard*	No dam	Low	Mod.	Full
3	*Seepage evident through dam*	None	Min.	Mod.	Large
4	*Ice-cored moraine dam +/- thermokarst features*	N/A	Min.	Partial	>Mod.
5	*Calving risk from ice cliff*	N/A	Low	Mod.	Large
6	*Ice/rock avalanche risk*	N/A	Low	Mod.	Large
7	*Supra- / englacial drainage*	None	Low	Mod.	Large

Multi-Criteria Analysis can be tailored for local range of hazards, not just lakes

Threshold parameter *Trigger potential parameter*

0	50	100	125	150+
Zero	Medium hazard	Serious	**High**	**Very high**
		>>> An outburst can occur at any time>>>		

(Modified from Dyce and Reynolds, 1998)

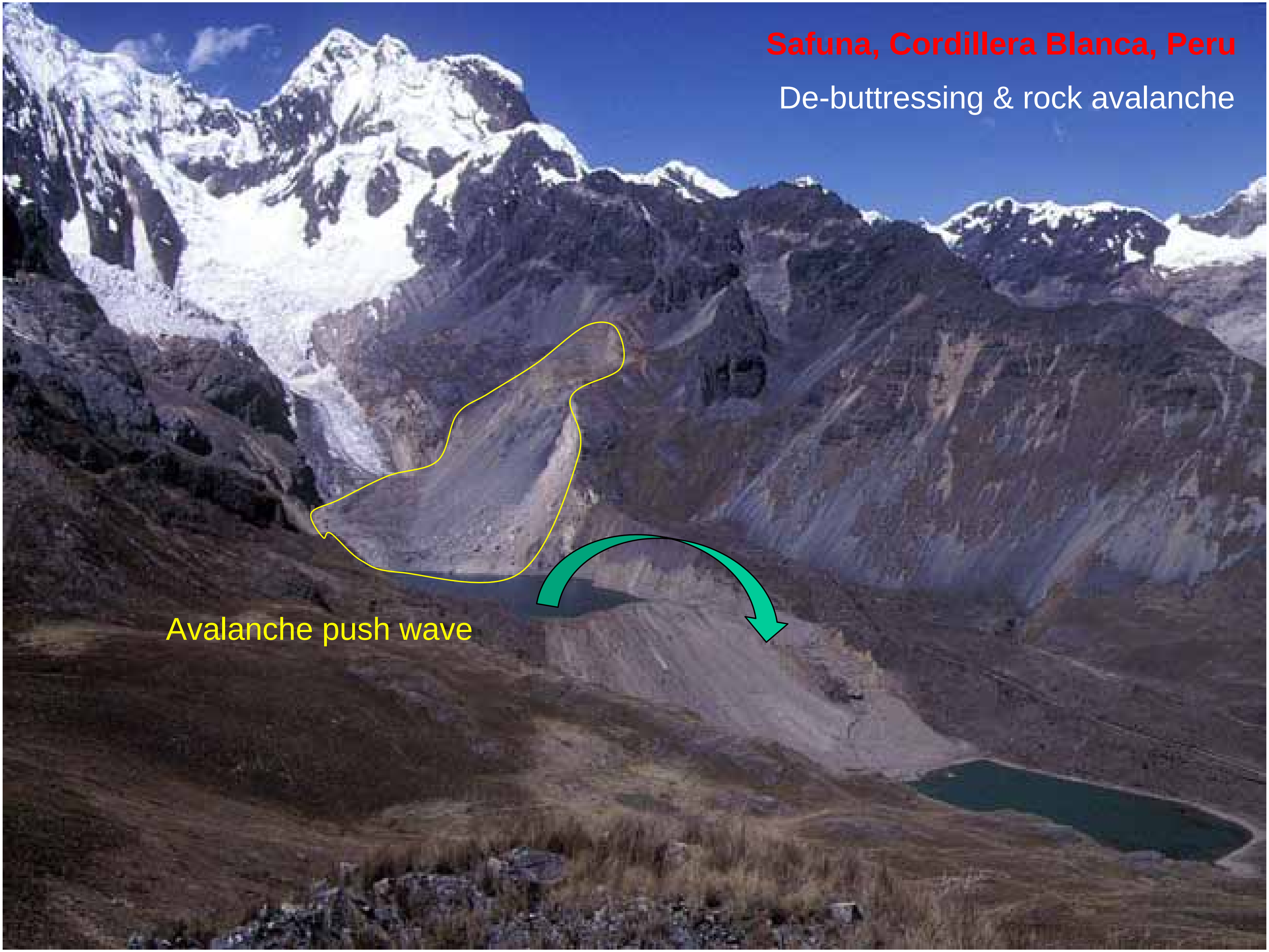

Multi-Criteria Analysis for northeast Nepal
Serious hazard
High hazard
Very high hazard
Medium hazard
Lake in China
b10/b19
b16
Hunku Shar Tsho (K)
Lower Barun Tsho (C)
Lumding Tsho
Chamlang Tsho (M)
b28
b32
b23/b26
Upper Barun Lake
Lake B
Lake J
Lakes F/O
Lake N
Imja Tsho
Tsho Rolpa
Minimal hazard
Lake L
Lake H
Lake G
Nagma Pokhari (A)
Medium hazard
Serious hazard
High hazard
Trigger Potential Index
Threshold Parameter Index
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

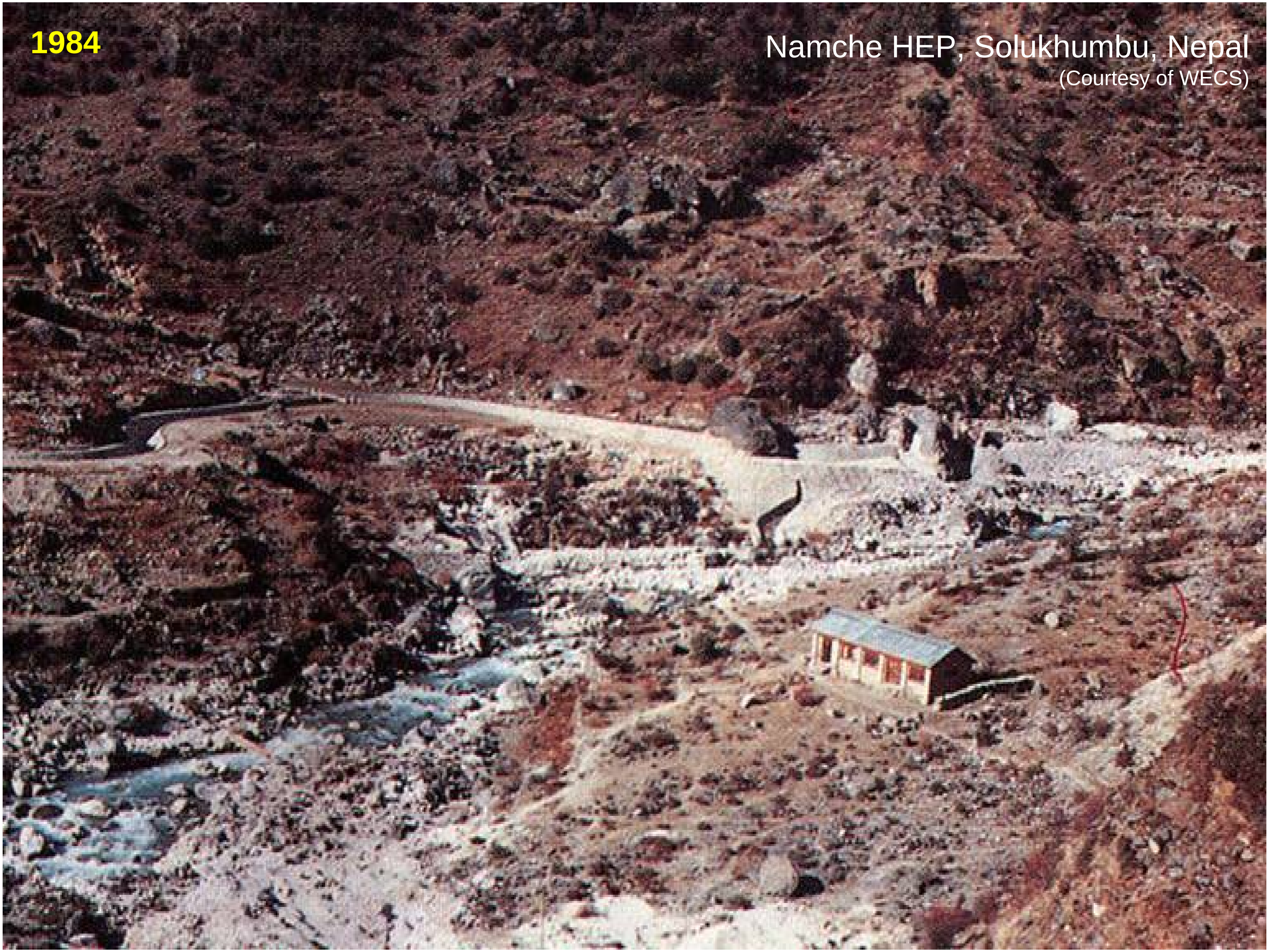
(RGSL, 2007)

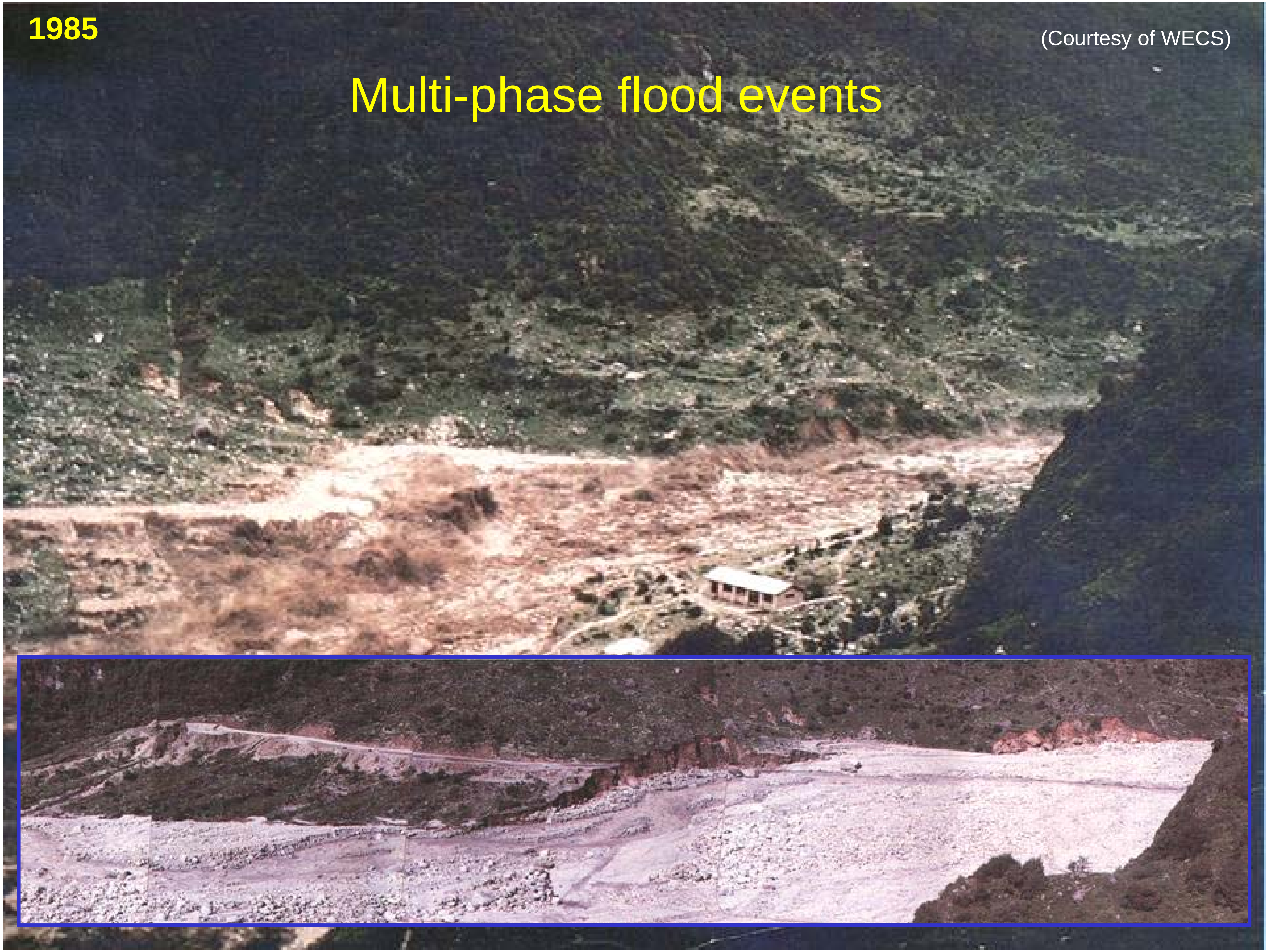
Changing hazards as a consequence of climate change

- Down wasting and receding glaciers
- Changes in melt water run-off – quantities and timing
- Changes in precipitation – quantities and timing
- Increased en-glacial melt-water storage?
- Thawing permafrost and geotechnical consequences
- Rise in boundary between cold-based and temperate ice regimes
- Increased lake temperatures and more rapid ablation of glacier cliffs that terminate in lakes
- Surge glacier damming – risk of ice dam failures
- Increasing number of glacial lakes forming

Increased rock and ice avalanche activity?


Safuna, Cordillera Blanca, Peru
De-buttressing & rock avalanche
Avalanche push wave


1984
Namche HEP, Solukhumbu, Nepal
(Courtesy of WECS)

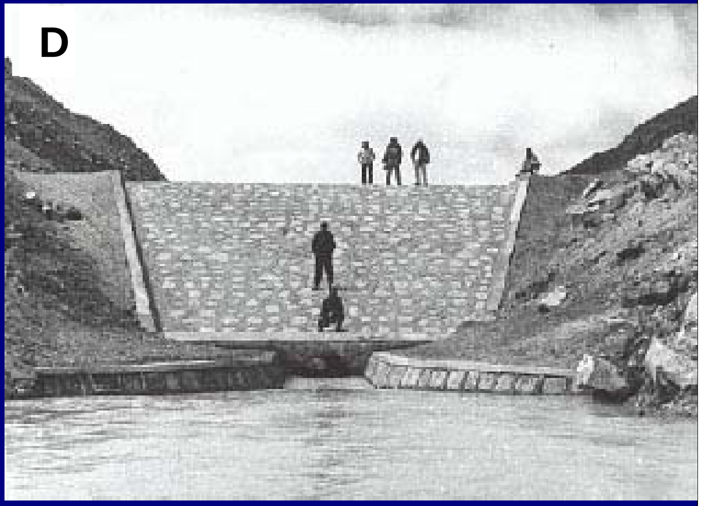

1985
(Courtesy of WECS)
Multi-phase flood events

Methods of remediation

Engineering remediation techniques have been used since 1941 in Peru:

A - Arhueycocha (open channel)
B - Laguna Llaca (channel and moraine dam rebuild)
C,D - Lago Hualcacocha (channel and moraine rebuild)

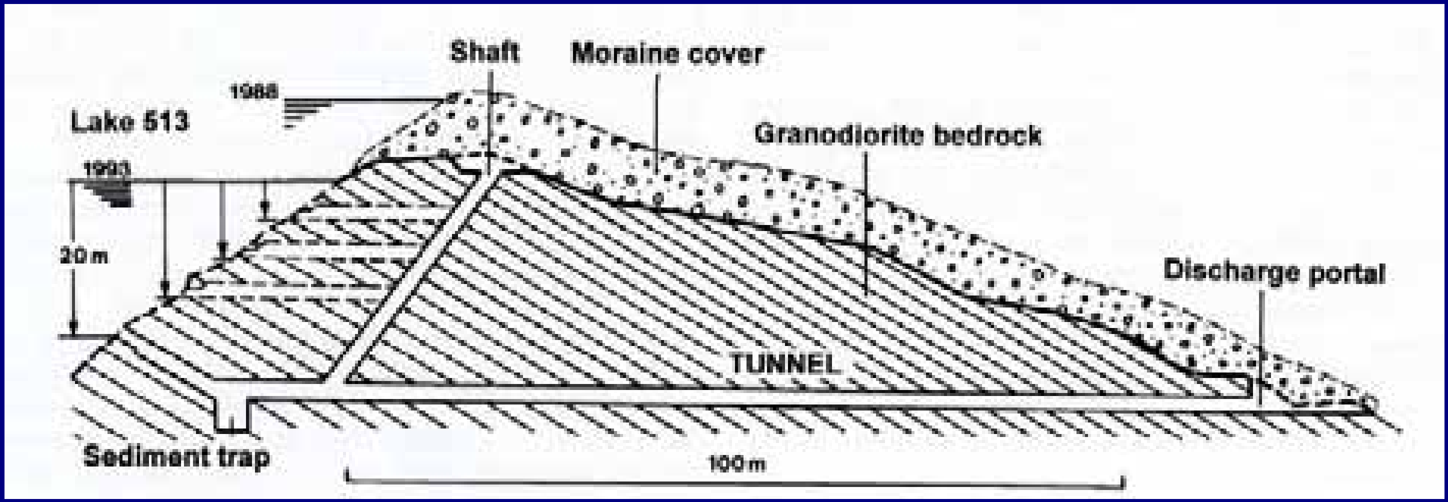
(C) USGS



(C) USGS

Hualcán, Cordillera Blanca, Peru

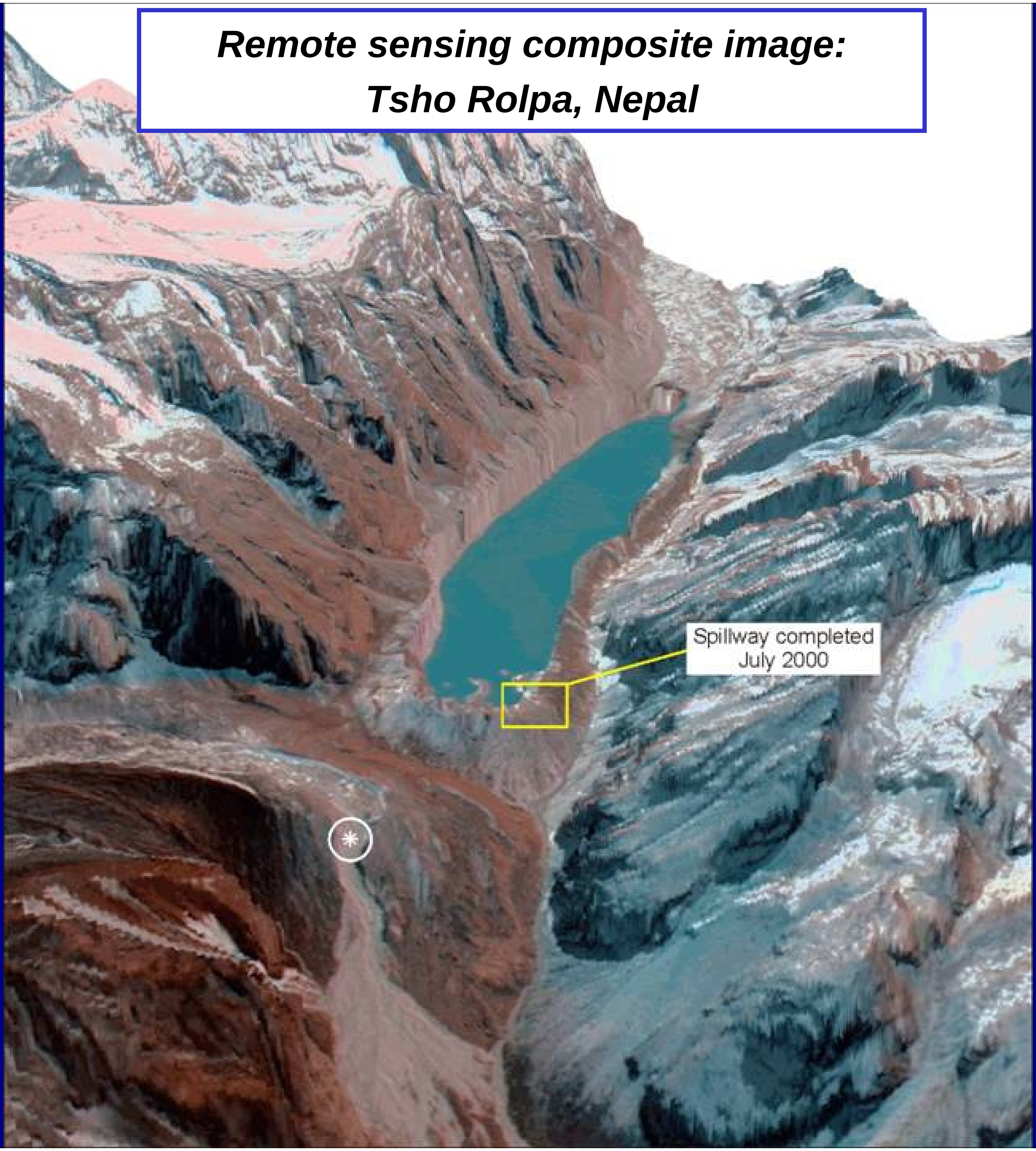
Hualcán, Peru



Reynolds *et al*. (1998)

Photo: C. Portocarrero, April 2010

Remote sensing composite image: Tsho Rolpa, Nepal



Tsho Rolpa, Nepal, mitigation

- Siphons installed 1995; tested until 1997
- Early Warning System installed 1998 – cost $1.2 million – destroyed

Tsho Rolpa - mitigation 2

- Channel construction 1999-2000

All heavy equipment airlifted by helicopter;
all else transported by porters & yaks.

Tsho Rolpa, Nepal

- Channel completed 2000
- Water level reduced by 3.5 m
- Cost ~ $3 million

Mitigation: Downstream

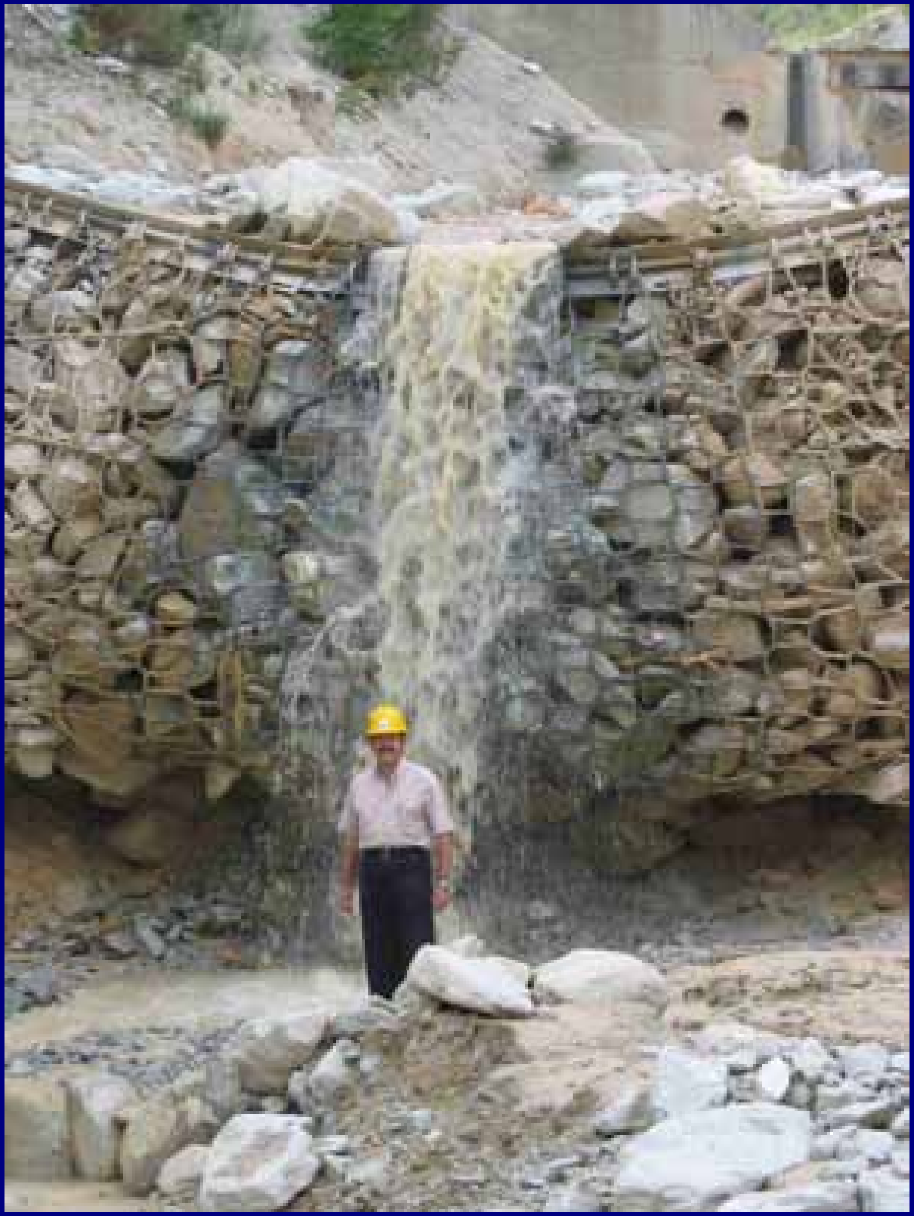


Photo courtesy of Dr Jorg Hanisch

Engineering works

- Debris flow retention netting
- Check dams
- Diversion channels & barriers
- Early Warning Systems

Vulnerability reduction

- Relocation
- Land use planning
- Risk reduction design

Combination of techniques

Conclusions: Glacial hazards

- Pose an increasing problem in response to changing climate;
- Identified hazards now likely to be different from those in 20-30 years time;
- Formation of particular glacial lakes can be anticipated perhaps >2-3 decades ahead;
- Some glaciers in Tajikistan are likely to form large lakes;
- Glacier surge activity should be closely monitored;
- Possibility of en-glacial outbursts in the future;
- Should be reviewed in key regions at least every five years, with some glaciers monitored every year using remote sensing;
- There is a need to plan ahead >3 decades for risk reduction


Glacial hazards – her future?
Thank you
for your attention
Reynolds International Ltd, UK

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