Glacial Hazards

Learning objectives

1. You know the general concepts of ‘hazard’ and ‘risk’, the differences between them, and how they are evaluated and applied
2. You know the hazards related to glacier mass changes, steep glaciers, and glacier lakes, and how they can evolve over time
3. You are able to roughly assess glacial hazards of an existing situation in an integrated view, considering all relevant aspects and processes

Terms and Concepts

Hazard / risk: Hazard, risk, intensity/magnitude (low/medium/high), probability of occurrence / return period, hazard map, damage potential, vulnerability.

Glacial hazards: length changes, glacier surges, debutressing due to glacier retreat; steep glaciers, ramp-/cliff–type glaciers, critical ramp slopes for temperate and cold glaciers, maximum runout distance; dam types (rock, moraine, ice), freeboard, dam geometry, typical outburst mechanisms for different dam types and related hydrographs (overflow; piping, retrogressive dam erosion, progressive breaching, mechanical failure;), flow transformations of outburst flows; integrative view on complex situations, process chains, active and passive protection measures.

References and Further Reading

Literature

Clague, J.J., Huggel, C., Korup, O., McGuire, B., 2012. Climate change and hazardous processes in high mountains. *Revista de la Asociación Geológica Argentina 69*, 328–338.

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

Korup, O., Tweed, F., 2007. Ice, moraine, and landslide dams in mountainous terrain. *Quaternary Science Reviews 26*, 3406–3422.

McColl, S., 2012. Paraglacial rock-slope stability. *Geomorphology*, 153-154: 1-16.

Richardson, S.D., Reynolds, J.M., 2000. An overview of glacial hazards in the Himalayas. *Quaternary International 65*, 31–47.

Worni, R., Huggel, C., Stoffel, M., 2012. Glacial lakes in the Indian Himalayas — From an area-wide glacial lake inventory to on-site and modeling based risk assessment of critical glacial lakes. *Science of The Total Environment*. In press.

Weblinks

Joint Standing Group on Glacier and Permafrost Hazards in Mountains (GAPHAZ): http://www.mn.uio.no/geo/english/research/groups/remotesensing/projects/gaphaz/

E-learning course from the University of Zurich: http://www.geo.uzh.ch/microsite/nathaz/ (username: nathaz, password: hamingat)

Additional Information

Hazard and risk

Hazard = f (Intensity, Probability of occurrence). Magnitude is used as a synonym for intensity.

Probability of occurrence p: Probability that a certain event happens (within a certain utility period). Return period T: period of time between occurrence of certain event. For glacial hazards, probability of occurrence is often a more appropriate concept (although difficult to determine).

Risk = f (hazard, damage potential). Mathematically, risk can be expressed as the product of hazard (H) and damage potential (D): $R = H * D$, where damage potential is a function of value (or number) of assets (e.g. buildings, infrastructure, people), and vulnerability.

Glacier length changes

Advancing glacier can overflow and destroy infrastructure, and cause damming and formation of potentially large reservoirs.
Glacier retreat can change the stress fields in steep rock walls and lead to a destabilisation over long periods (on the time scales of decades to millennia)
Both advance and retreat can lead to new ice avalanche situations. Glacier retreat has caused the formation and/or growth of glacier lakes in many regions.

Ice avalanches

Discrimination between ramp- and edge- (cliff-) type starting situations. For temperate (cold) glaciers an approximate minimum slope threshold of 25° (45°) is given, based on empirical data from the Alps in Europe. Situations exceeding this threshold can be considered as potentially unstable.

Glacial lakes

Depending on the dam properties, different outburst mechanisms have to be considered:

Moraine dams

Overtopping and retrogressive incision: Overtopping => initiation of erosion => enlargement of the breach => increase of outburst discharge (positive feedback). Such outbursts typically develop over a few hours.
Piping: In case of a small freeboard and a large hydraulic gradient: Groundwater flow through dam => enlargement of drainage channels => collapse of the dam crest above pipe.
Instabilities: weak geometry (low width to height ratio) and/or dead ice / permafrost degradation in the dam can weaken the dam or cause saturation and subsequent failure (sliding) of the low-cohesion dam material.

Ice dams

Progressive breaching (hydraulic break): Progressive extension of subglacial flow channels can occur due to friction heat and/or ice dam flotation. This is normally terminated by a sudden closure of the channels when the ice pressure exceeds the water pressure. Such outbursts develop over many hours up to a few days.

Mechanical breaching (‘sudden’ outburst): Rapid drainage with extremely high discharges. Normally restricted to dams consisting of ice debris or ice blocks from previous ice avalanches or surges. Such outbursts typically develop over a few hours (breach processes are similar as for moraine dam breaches)

Outburst triggers

Rockfall, ice and snow avalanches, calving, debris flows, an influx of water caused by sudden drainage of an upstream lake, or heavy rainstorms can generate impact waves that trigger lake outbursts. As a result especially small lakes can drain completely.

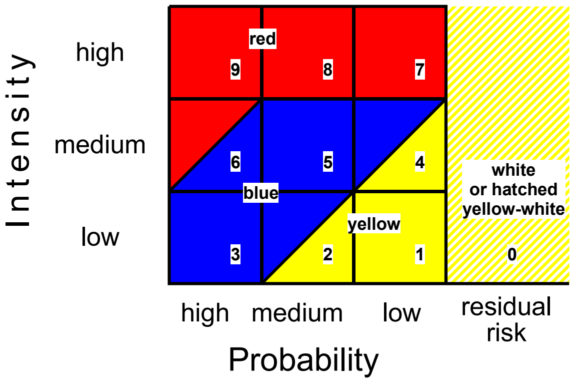
Evolution over time

High-mountain environments undergo rapid changes: Glacier fluctuations can change ice avalanche disposition situations, influence the evolution of glacier lakes, and change the stress fields of steep slopes. Changes in temperatures can affect the thermal regime at the base of hanging glaciers and thus change their stability; warming of permafrost has an influence on the stability of rock walls and on potential dead ice remnants in moraine dams.

Glacier related catastrophes are often the result of chain reactions of interacting processes. This requires integrative views and frequent re-assessments of complex situations.

ANNEXED MATERIAL

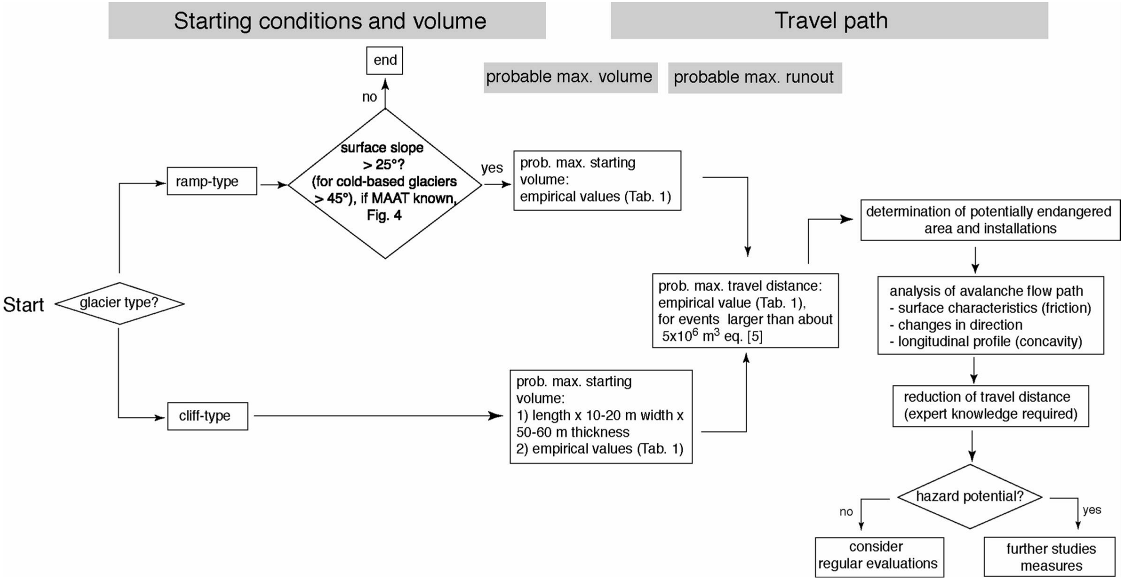
Scheme for the determination of hazard levels (valid for Switzerland) (from Raetzo et al., 2002). (Yellow = low hazard, blue = medium hazard, red = high hazard)



Empirically based maximum values of different hazard processes for the European Alps (from Huggel et al., 2004)

Maximum hazard-related process magnitudes	**empirically-based values**
max. ice avalanche starting volume (ramp- type)	$5x10^6$ m^3
max. ice avalanche starting volume (edge- type)	$4x10^5$ m^3
max. outburst volume, subglacial water reservoirs	$3x10^6$ m^3
max. discharge, subglacial water reservoirs	$1\text{-}2x10^2$ m^3/s
max. ice avalanche runout (min. average slope)	17° (31%)
max. lake outburst flood runout (debris flow)	11°
max. lake outburst flood runout (flood wave)	2-3°
max. sediment yield along channel (debris flow, in large moraine bastions, per channel length unit)	700 m^2
critical channel slope for erosion (debris flow)	8°

Assessment procedure for hazards related to ice avalanches (from Huggel et al., 2004)



Assessment procedure for hazards related to glacier lake outburst floods (from Huggel et al., 2004)