Geophysical Research Abstracts,
Vol. 10, EGU2008-A-03165, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-03165
EGU General Assembly 2008

Modelling the formation of future glacial lakes by means of GIS-based methods

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The predicted atmospheric warming during the 21st century potentially will lead to retreating, downwasting, collapsing and even complete vanishing of mountain glaciers all over the world. The associated exposure of overdeepened parts of glacier beds can result in lake formation. In connection with rock- and ice avalanches, outbursts of these lakes are a potential source of serious flood and debris flow hazards. They can pose a significant threat to people and infrastructure, especially in densely populated high mountain areas such as the Alps, the Andes or the Himalayas and other regions. Thus, methods for early detection of sites with potential lake formation are important for developing protection concepts dealing with hazards in the rapidly changing high-mountain environment. This contribution presents GIS-based methods and models for different levels of detail which are tested in the Swiss Alps but could be applied all over the world.

In order to get a large area overview, an analysis of a digital elevation model (DEM) in combination with glacier outlines and further surface characteristics is performed. Assuming a constant basal shear stress and, hence, slope-dependent thickness variability, sites with potential future lake formation are modelled. We applied a simple and a more sophisticated approach: First, by selecting major glacier surfaces with slopes $< 5^\circ$ and secondly a reconstruction of the glacier bed from GIS-based modelling. Then, further criteria that enhance the probability of an overdeepening in the glacier bed are applied: (1) A break in the glacier surface slope; (2) regions with compressive flow (no crevasses) followed by extensive flow (heavily crevassed); and (3) an enlarged width followed by a narrow glacier part.

It is also important to distinguish between glaciers with a rocky or a sedimentary bed, as sub- and periglacial sedimentation can fill overdeepenings quite rapidly and thus reduce the probability of lake formation. On the other hand, lakes in a sedimentary bed have an increased hazard potential. An index for glacier sedimentation is extracted from the DEM with GIS-based methods.

In combination with a GIS-based scenario of glacier shrinkage for the Alps, the growth of new lake surfaces in Switzerland can be estimated as a function of the increase of the equilibrium line altitude (ELA), neglecting size dependent dynamic response times but assuming a 25 year response time for all glaciers. However, a total of several dozen square kilometers of lakes may indeed form during the 21st century with about half of it developing already within the first few decades.

The Rhone- and Trift glaciers in the Swiss Alps are used for the verification of the methods with currently observed lake developments. Future scenarios of potential lake formation are shown for the Aletsch- and Stein glacier.