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New glacial and periglacial lakes in warming mountain areas: potential outburst mechanisms and hazard assessments

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Continued if not accelerated rise of atmospheric temperature causes rapid shrinkage of glaciers and degradation of permafrost in cold mountain areas all over the world. As a consequence, a great number and variety of glacial and periglacial lakes form in steep topography and increasingly destabilized environments, especially in connection with the retreat or disintegration of glaciers. Such lakes to a certain degree replace the loss of landscape attractiveness from vanishing glaciers but at the same time constitute a serious, newly evolving, rapidly changing and far-reaching natural hazard potential. Digital terrain information as combined with satellite data and GIS-based glacier modelling enables to anticipate and monitor the location, development and geometry of such future water bodies and their environment as a function of climate scenarios. This opens the possibility for early assessment of possible future threats and initiation of corresponding mitigation options. Besides vulnerability aspects of settlements and infrastructure, damages related to outbursts from high-mountain lakes first of all depend on peak discharge and flood propagation, which in turn are a function of (a) trigger and outburst mechanisms at the lakes and (b) downstream channel characteristics. A main challenge consists in adequate consideration of all possible mechanisms, their combinations and chain reactions. Even very small lakes and relatively low peak discharge can cause devastating debris flows to form on steep slopes covered with talus or moraine material. Depending on the lake environment, progressive enlargement of subglacial channels is a possible but often not the most dangerous outburst process. Large uncertainties involved with boundary and initial conditions

of related numerical models (for instance, channel geometry, roughness and material) hardly permit reliable estimates and necessitate the use of empirical worst-case estimates. Similarly and given the many unknowns, using empirical worst-case values is often the most feasible procedure for sudden rupture of dams consisting of broken ice from surges or ice avalanches or for breaching of moraine dams through piping, slope instability or retrogressive erosion, which both can lead to extreme peak flows with serious impacts. The largest potential catastrophes may be caused by rock, ice or combined rock/ice avalanches, which reach natural, artificial or newly forming lakes. The probability of such events is especially enhanced where permafrost inside rock walls is deeply warming to near-zero temperatures known to be critical for slope stability, and where disappearing glaciers cause loss of support for over-steepened rock walls. Combinations of these two aspects occur in many cases and are becoming more and more widespread as a consequence of rapid ice decay and subsurface temperature rise. Assessment of hazard potentials from new glacial and periglacial lakes in warming mountain areas must therefore necessarily include stability considerations relating to adjacent perennially frozen and potentially deglaciated rock walls.