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# Insights from analyzing and modelling cascading multi-lake outburst flood events in the Santa Cruz Valley (Cordillera Blanca, Perú)

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Abstract: Since the end of Little Ice Age, the Cordillera Blanca of Perú has experienced tens of lake outburst floods (LOFs), resulting in the loss of thousands of lives and significant material damages. Most commonly involving glacial lakes, such events are often directly or indirectly related to glacier retreat. Here we analyze an event on 8th February 2012 involving four lakes and affecting two valleys (Santa Cruz and Artizón) in the northern part of the Cordillera Blanca. Using the combination of field data, satellite images, digital elevation model (DEM) and GIS-based modelling approaches, the main objectives are: (i) to better understand complex multi-lake outburst flood and related foregoing and induced geomorphological processes; and (ii) to evaluate and discuss the suitability, potentials and limitations of the r.avaflow model for modelling such complex process chains.

Analyzing field geomorphological evidence and remotely-sensed images, we reconstruct the event as follows: a landslide from the recently deglaciated left lateral moraine of Lake Artizón Alto (4 639 m a.s.l.), characterized by steep slopes and a height of more than 200 m produced a displacement wave which overtopped the bedrock dam of the lake. The resulting flood wave breached the dam of the downstream moraine-/landslide-dammed Lake Artizón Bajo (4 477 m a.s.l.), decreasing the lake level by 10 m and releasing 3 x 105 m3 of water. Significant amounts of material were eroded from the steeper parts of the Artizón Valley (mean slope >15°) and deposited further downstream in the flatter part of the Santa Cruz Valley (mean slope <2°; confluence of the two valleys at 3 985 m a.s.l.). The flood affected two debris cone-dammed lakes (Jatuncocha and Ichiccocha) in the Santa Cruz Valley. Some minor damages to the dam of Lake Jatuncocha were documented. Geomprohological evidence of the event was observed more than 20 km downstream from Lake Artizón Alto.

The described multi-LOF event was employed as a particularly challenging test case for the currently developed, GIS-based two-phase dynamic mass flow model r.avaflow. Whilst the test results are very promising, lessons learned for r.avaflow model are the need for (i) an improved concept to determine the flow boundaries; and (ii) thorough parameter tests. High demands on the resolution and quality of the DEM are revealed.

From our event and modelling analysis we conclude the following: mass movements in the headwaters of hydrologically connected lake and river systems may affect the catchment in complex and cascading ways. Flood and mass flow magnitudes can be both intensified or attenuated along the pathway. Geomorphological analysis and related modelling efforts may elucidate the related hazards as a basis to reduce the associated risks to downstream communities and infrastructures.

Keywords: cascading processes, dam failure, glacial lake outburst flood (GLOF), high-mountain lakes, r.avaflow