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Landslide-generated tsunamis in a perialpine lake: Historical events and numerical models

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Many of the perialpine lakes in Central Europe – the large, glacier-carved basins formed during the Pleistocene glaciations of the Alps – have proven to be environments prone to subaquatic landsliding. Among these, Lake Lucerne (Switzerland) has a particularly well-established record of subaquatic landslides and related tsunamis. Its sedimentary archive documents numerous landslides over the entire Holocene, which have either been triggered by earthquakes, or which occurred apparently spontaneously, possibly due to rapid sediment accumulation on delta slopes. Due to their controlled boundary conditions and the possibility to be investigated on a complete basinal scale, such lacustrine tsunamis may be used as textbook analogons for their marine counterparts.

Two events in the 17th century illustrate these processes and their consequences: In AD 1601, an earthquake (Mw $\sim$ 5.9) led to widespread failure of the sediment drape covering the lateral slopes in several basins. The resulting landslides generated tsunami waves that reached a runup of several metres, as reported in historical accounts. The waves caused widespread damage as well as loss of lives in communities along the shores. In AD 1687, the apparently spontaneous collapse of a river delta in the lake led to similar waves that damaged nearby villages.

Based on detailed information on topography, bathymetry and the geometry of the landslide deposits, numerical simulations combining two-dimensional, depth-averaged models for landslide propagation, as well as for tsunami generation, propagation and inundation, are able to reproduce most of the reported tsunami effects for these events. Calculated maximum runup of the waves is 6 to >10 m in the directly affected lake basins, but significantly less in neighbouring basins. Flat alluvial plains adjacent to the most heavily affected areas are inundated over distances of several hundred metres.

Taken as scenarios for possible future events, these past events suggest that tsunami hazard in these lake should not be neglected, although they are infrequent and the effects are naturally limited to the immediate surroundings of the affected basins. The shores of Lake Lucerne, as well as of many other perialpine lakes, are nowadays densely inhabited and host considerable infrastructure, so that events similar to those reported may have serious consequences. Identification and mapping of possible subaquatic landslide source areas, the inclusion of geotechnical data on potentially mobile sediments, as well as numerical modelling of tsunamis are thus important components of a proper hazard assessment for these lakes.