Tsunami-hazard assessment for a perialpine lake: subaquatic morphological mapping, slope-stability analysis and inundation modeling

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INTRODUCTION

Historical reports from the past centuries as well as studies investigating the sedimentary archives of the large perialpine lakes of Central Europe show that the shores of these lakes have repeatedly been hit by tsunami-type waves with heights of several meters that were generated by subaquatic landslides. The best-known event of this kind occurred on Lake Lucerne (Central Switzerland) in AD 1601, when an MW ~ 5.9 earthquake with an epicenter in the vicinity of the lake triggered numerous subaquatic slope failures in several basins of the lake. The resulting waves reached heights of more than 5 m, inundated extensive areas on the lakeshore and caused several fatalities. While reconstructions of such events suggest that landslide-generated tsunami-type waves and associated flooding are a natural hazard in this environment, a quantification of this hazard, with predicted intensities and recurrence rates, has largely been missing so far. Considering the significantly increased vulnerability on the nowadays often densely populated lake shores, a thorough analysis of the potential for such waves seems necessary.

METHODS

We present results of a study evaluating the flooding hazard posed by landslide-generated tsunamis for a part of Lake Lucerne. The mechanism of the predominant type of slope failures responsible for wave generation is known from previous studies - the failures typically affect a drape of lacustrine sediments on submerged non-deltaic slopes and have a well-defined failure surface. The approach for hazard assessment involves several steps, from the identification of potentially unstable sediments over slope-stability analyses to wave propagation and inundation modeling (Figure). High-resolution bathymetry data and a dense grid of reflection seismic profiles provide the basis for the mapping of potentially involved areas and currently available sediment volumes on «charged» slopes. Using geotechnical data and a simple model from previous studies, the areal distribution of the slope stability (factor of safety) can be evaluated for a given external (i.e. seismic) load. Contiguous areas with a factor of safety < 1 are considered unstable under the given load and used as «scenarios» describing the initial geometries of wave-generating mass movements. For over 30 identified scenarios with volumes between 0.1 and 5.4 million cubic meters, mass-movement propagation (using Bingham rheology), wave generation as well as propagation and inundation of land (using nonlinear shallow-water equations) areas have been modeled using open-source software.

RESULTS

Visualization of the results relies mainly on combined «intensity maps» and show the maximum intensity reached for any of the scenarios. The maps are similar to those used in common flood hazard mapping and include three intensity classes (low, medium, high) that are defined based on both flow depth and flow momentum (product of flow velocity and depth). The current maps are based on a «worst case» earthquake scenario with a recurrence rate of several thousand years. The maps thus designate a residual hazard, as the timescale is longer than the periods covered by the usual hazard maps. However, even substantially larger events cannot be excluded due to the uncertainties adding up for the different steps of the assessment. Compared to the area flooded in the AD 1601 event, the extent of the potentially affected area on the intensity map is nevertheless often significantly smaller, an effect that is caused by the reduced availability of potentially mobile sediments on the slopes which have failed during the AD 1601 event.

CONCLUSION AND OUTLOOK

Future improvements to the approach may include e.g. the inclusion of other wave-generating processes, such as rockfalls impacting the lake and large-scale failures of delta slopes. Moreover, the change from deterministic, scenario-based modeling to a probabilistic method using recurrence rates and parameter ranges for the input variables will offer new perspectives

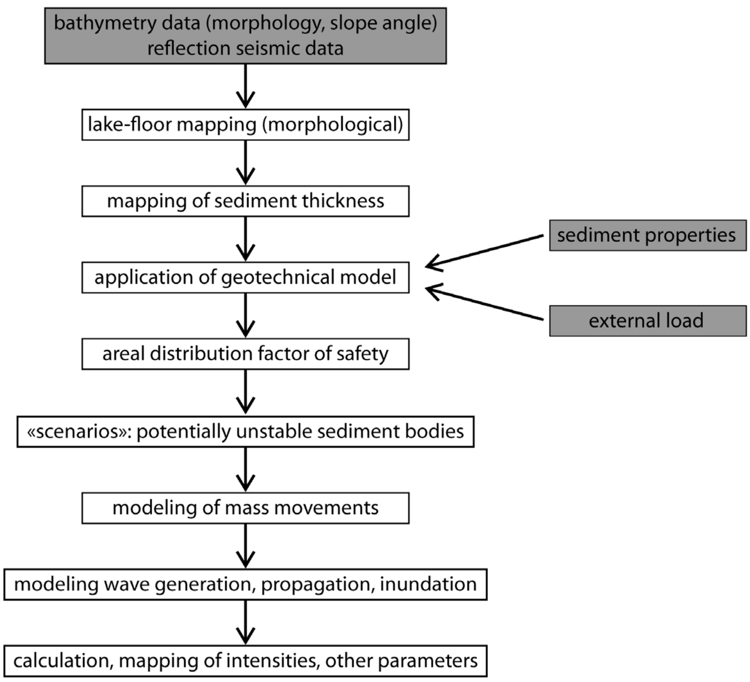

Figure 1. Schematic diagram showing the process of a (deterministic) hazard assessment for lake tsunamis.

KEYWORDS

perialpine lakes; subaquatic mass movements; wave modeling

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