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# Moraine-dammed lake failures in Patagonia and assessment of outburst susceptibility in the Baker Basin

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**Abstract.** Glacier retreat since the Little Ice Age has resulted in the development or expansion of hundreds of glacial lakes in Patagonia. Some of these lakes have produced large ($\geq 10^6$ m$^3$) Glacial Lake Outburst Floods (GLOFs) damaging inhabited areas. GLOF hazard studies in Patagonia have been mainly based on the analysis of short-term series ($\leq 50$ years) of flood data and until now no attempt has been made to identify the relative susceptibility of lakes to failure. Power schemes and associated infrastructure are planned for Patagonian basins that have historically been affected by GLOFs, and we now require a thorough understanding of the characteristics of dangerous lakes in order to assist with hazard assessment and planning. In this paper, the conditioning factors of 16 outbursts from moraine-dammed lakes in Patagonia were analysed. These data were used to develop a classification scheme designed to assess outburst susceptibility, based on image classification techniques, flow routine algorithms and the Analytical Hierarchy Process. This scheme was applied to the Baker Basin, Chile, where at least seven moraine-dammed lakes have failed in historic time. We identified 386 moraine-dammed lakes in the Baker Basin of which 28 were classified with high or very high outburst susceptibility. Commonly, lakes with high outburst susceptibility are in contact with glaciers and have moderate ($> 8°$) to steep ($> 15°$) dam outlet slopes, akin to failed lakes in Patagonia. The proposed classification scheme is suitable for first-order GLOF hazard assessments in this region. However, rapidly changing glaciers in Patagonia make detailed analysis and monitoring of hazardous lakes and glaciated areas upstream from inhabited areas or critical infrastructure necessary, in order to better prepare for hazards emerging from an evolving cryosphere.

## 1 Introduction

Amongst the most frequent and damaging processes related to glaciers are Glacial Lake Outburst Floods (GLOFs). The failure of glacial lakes can release millions of cubic metres of water in a short time (minutes to days) and produce floods with high peak discharges ($10^4$m$^3$ s$^{-1}$) and remarkable erosive and transport capacity (Costa and Schuster, 1988; Breien et al., 2008). GLOFs can occur through different mechanisms. Moraine-dammed lakes commonly fail due to overtopping and the progressive enlargement of a breach in the dam. Rainfall, meltwater and waves produced by mass movements, ice avalanches or calving often trigger the overflow and subsequent moraine-dam failures (Costa and Schuster, 1988; Emmer and Cochachin, 2013). Piping after earthquakes, the mechanical failure of ice-cored moraines and flow waves from upstream lake failures have also been related to GLOFs (Lliboutry et al., 1977; Buchroithner et al., 1982).

In the Himalayas, European Alps and the Andes GLOFs have affected mountain communities for centuries, resulting in thousands of casualties (Hewitt, 1982; Grove, 1987; Reynolds, 1998). However, the generation of new glacial lakes as a consequence of glacier retreat, and the economic exploitation of previously uninhabited valleys make the emergence of new endangered areas likely. For example, in Chilean Patagonia, hydroelectric generation plants are being planned in areas that have historically been influenced by GLOFs (Dussaillant et al., 2009; Vince, 2010). Thus, there is now an urgent need to better understand and assess the GLOF hazard in these regions where detailed analyses are lacking.