HESS-2015-512-Discussions

Modeling glacial lake outburst flood process chain: the case of Lake Palcacocha and Huaraz, Peru

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Response to the Comments of Reviewer 2

The authors greatly appreciate the insightful and constructive comments of Anonymous Reviewer #2 that helped us to improve the paper.

General comments

General Comment 1:

Abstract, line 8 and Study area,p.7 line 25. There are different estimations of number of victims during catastrophic GLOF in 1941 exist. For example, Mark Carey (Mark Carey, In the Shadow of Melting Glaciers: Climate Change and Andean Society, 2010, DOI:10.1093/acprof:oso/9780195396065.003.0002) wrote, that "glacial lake outburst flood in 1941 killed 5,000 people and destroyed one-third of the Ancash capital city of Huaraz". So, it is may be better to give several references in one place (for example, in the Study area description).

- **Response to General Comment 1:**

While it is true that Carey (2010) does cite a figure of 5000 deaths as a result of the 1941 Lake Palcacocha GLOF, more recently Wegner (2014) examined the historical records of the Peruvian Red Cross and reports that "According to the final data of the Red Cross itself and the Peruvian government, they calculated, a week after the events, that the dead were around 1800 in addition there were 400 wounded and nearly 1500 families homeless (Peruvian Red Cross, 2004:213)." On page 7, Line 25-27, in fact several references are cited including Carey (2010) and Wegner (2014).

Wegner, S. A.: Lo Que el Agua se Llevó: Consecuencias y Lecciones del Aluvión de Huaraz de 1941, Technical Note 7 of the series "Technical Notes on Climate Change", Ministry of Environment, Lima, Peru, 88 pp., 2014.

Cruz Roja Peruana (2004) Una idea, una acción ; 125 años de la Cruz Roja Peruana. Texto : Carlos Batalla Sotelo. Lima. Tarea Educación Gráfica Educativa. 412 p.

Carey, M.: In the Shadow of Melting Glaciers: Climate Change and Andean Society, Oxford Univ. Press, New York, 2010.

General Comment 2:

P.8 Study area. As shown in the fig.1, there are several other river branches with lakes in the area above Huaraz city. Does any possibility of their outburst exist? Or Lake Palcacocha is only one potentially dangerous lake in the basin? It could be interesting to the reader.

- **Response to General Comment 2:**

There are several lakes upstream Huaraz, Lake Palcacocha being the largest, Tullparaju, and Cuchillacocha Lakes being somewhat smaller. We have not done any work on the lakes that the reviewer is referring to except for Palcacocha. Therefore, we cannot report if those lakes are potentially dangerous or not. There is an effort in Huaraz to study those lakes, and three of the coauthors are part of that effort; however, this is out of the scope of this paper and at this point we don't have information to contribute with solid data that support any statement.

General Comment 3:

P. 14 Moraine erosion simulation. It is not rare case in the glaciated areas, when moraine dam contains ice or frozen patterns. In such case dam erosion process during outburst flood has other mechanism and erosion can be larger. Whether the damming moraine of Lake Palcacocha may contain ice? This point should be mentioned and discussed.

- **Response to General Comment 3:**

We believe that the Lake Palcacocha terminal moraine does not contain ice, since: (1) there are two structures that reinforce the terminal moraine that are stable and don't show any sign of instability due to ice core melting after several decades of being installed; (2) there is no sign of small collapses on the top of the moraine indicating thermostat activity in the moraine; (3) we have not found ponds formed on the surface of the moraine during our site visits which would indicate melting ice inside; (4) there is no seepage in the surface of the exposed scar of the 1941 GLOF as one walks up from the valley below; and there is no presence of seepage at the toe of the existing moraine. In fact, Vilímek et al. (2005) noted the ponds that have formed in the valley below the toe of the moraine and they report "The location of the ponds along with the observed inflow on their floors favours their seepage origin over pond's formation due to stagnant ice blocks." (Vilímek et al., 2005:111), further "…no evidence proving presence of stagnant ice inside the moraine was found within the Palcacocha Lake area." (Vilímek et al., 2005:112).

Vilímek, V., Zapata, M. L., Klimes, J., Patzelt, Z., and Santillan, N.: Influence of glacial retreat on natural hazards of the Palcacocha Lake area, Peru, Landslides, 2, 107–115, doi:10.1007/s10346- 005-0052-6, 2005.

General Comment 4:

P.18. Inundation simulation. FLO-2D model chosen for inundation simulation, doesn't take into account additional erosion and subsequent accumulation of debris during flood wave moving. However, there are several zones of erosion and accumulation of debris from 1941 GLOF along the Paria River, and the same additional erosion and accumulation could be expected for the next GLOF event. Such redeposition is very difficult take into account during modelling, but this model limitation should be mentioned.

- **Response to General Comment 4:**

We agree with the reviewer. There would be considerable erosion and deposition along the river. Flo2D does not estimate erosion when the debris flow module is activated. Additionally, we did not have enough field information to perform such a study. Consequently, we used a prescribed sediment concentration by volume of 50%, which is an upper limit of values recommended in the literature and by the FLO-2D developers (FLO-2D, 2012). We have added discussion of this issue in the revised paper, Page 31 line 12 after the dot:

Old Text: "In this work, a fixed concentration of 50% by volume was used, which is a good upper limit according to the literature, but it may be too high if the solid material available for erosion is not sufficient in the inundation path."

New Text: "A potential GLOF will erode the bank along the river, especially where lateral moraines are present (XS 3), scouring, transporting and depositing soil many times as the flood moves downstream from the lake to the city. Flo2D does not represent this process when using the Mudflow module. Additionally, we did not have field information to perform a study of these effects. Therefore, in this work, a fixed sediment concentration of 50% by volume was used, which is a good upper limit according to the literature and the FLO-2D developers (FLO-2D, 2012), but it may be too high if the material available for erosion is not sufficient in the inundation path."

General Comment 5:

P.21 3.6 Hazard identification. To my opinion, it is better to use term "potential hazard" instead "hazard" for described hazard zonation.

- **Response to General Comment 5:**

In the response to Reviewer 1 General Comment 5 we have changed the term "hazard map" to "preliminary hazard map" in recognition that the hazard indicated from modeling results will need to be verified and validated in the field with observations and data. Here, we propose to change the text of the paper to read:

Old Text: “The flooding intensity for various likelihood events are used to prepare a hazard map that will allow communication to the affected community of the hazard at various locations and can facilitate planning, regulation, and zoning based on the map”

New Text: “The flooding intensity for various likelihood events are used to prepare a preliminary hazard map that will allow communication to the affected community of the potential hazard at various locations and can facilitate planning, regulation, and zoning based on the map”

General Comment 6:

P.4 line 10 Fischer et al., 2012) –left parenthesis is missed

- **Response to General Comment 6:**

We appreciate that the reviewer pointed this out. We have corrected this.