Final Author Comments: Response to Reviewers

Journal: HESS Title: Assessing Downstream Flood Impacts Due to a Potential GLOF from Imja Tsho in Nepal Author(s): Marcelo A. Somos-Valenzuela, Daene C. McKinney, Alton C. Byers, David R. Rounce, Cesar Portocarrero, Damodar Lamsal MS No.: hess-2014-420

Anonymous Referee #1

Short comments:

Comment 1

Page 13021, line 6: here is described moraine and "ice-cored outlet complex". I suppose that this is moraine as well. Is it front moraine? Not clear, why "outlet complex"? It looks like a supraglacial lake from the Fig. 1, but this is not mentioned clearly (only on p. 13021, l. 15). Please write clearly what type of the lake is in the beginning before the description of the lake.

Response to Comment 1:

The referee is correct in its interpretation of Figure 1, Imja Tsho (or Imja Lake) is a supraglacial lake formed on top of the Imja glacier, from where it gets its name. What is defined as an "ice-cored outlet complex" corresponds to the terminal moraine of the Imja glacier at its last maximum extent. The term "ice-cored outlet complex" was used to highlight the fact that the terminal moraine complex is ice cored and has an outlet that drains Imja Tsho. Therefore, the paragraph from line 3 to 6 in page 13021 has been revised following the comment and now it reads:

"Imja Tsho, located in the Khumbu region (27.9_N, 86.9_E, Fig. 1), is a supraglacial lake formed on top of Imja glacier, and it is bounded on the east by the Lhotse-Shar and Imja glaciers, on the north and south by lateral moraines, and to the west by a 700m wide by 700m long ice-cored terminal moraine complex that has an outlet that drains the lake feeding into the Imja Khola river (Watanabe et al., 2009; Somos-Valenzuela et al., 2013)."

Comment 2:

Several lakes are mentioned in the Introduction but only Imja is in Fig. 1. And here is "Imja Tsho" and in the text only Imja. Is Tsho = Lake ?? Not clear?

Response to Comment 2:

Yes, Imja Tsho and Imja Lake are equivalent names and the word "Tsho" means "Lake" and is commonly used to refer to glacial lakes in Nepal. We have changed the manuscript to use the term Imja Tsho throughout the paper to avoid the confusion.

Comment 3:

What is the elevation of the lake level?

Response to Comment 3:

The elevation of the lake is 5010 m above mean sea level and it is indicated in Line 22 page 13023.

Comment 4:

Page 13024, lines 1: here is the influence of piping and earthquakes described. Next sentence introduced "other factors", nevertheless the same factors (!) are mentioned again (lines 4 +5).

Response to Comment 4:

The reviewer is correct and the text was mistakenly repeated. Therefore the paragraph has been revised from lines 2 to 5 in page 13024, after Somos-Valenzuela et al. (2013) and now it reads:

"Other factors that may trigger a GLOF from Imja Tsho include excessive rain and potential blockage of the outlet that may be produced by ice calved at the glacier terminus."

Comment 5:

Page 13030: line 15: some villages are mentioned (e.g. Phakding), but not in the Fig. 1.

Response to Comment 5:

One purpose of Figure 1 is to show the location of Imja Tsho. Phakding is located about 45 km downstream and we have included it in a new version of Figure 1.



Figure 1. Location of Imja Tsho in the Khumbu region of Nepal.

Comment 6:

Page 13031: l. 26: the situation 30 years ago is described –it will be good to have a new Fig (e.g. a sequence of several satellite images from various years) in the paper where glacier retreat and growing lake will be visible.

Response to Comment 6:

This is a very good suggestion. The evolution of the lake from 1992 to 2012 has been shown and described in Somos-Valenzuela et al. (2014) and Watanabe et al. (2009) have illustrated the development of the lake form the early 1960s and those references have been added to the manuscript at this point. The manuscript has been changed to read:

"The hazard of an Imja Tsho GLOF didn't exist 30 years ago (see Somos-Valenzuela et al. (2014) and Watanabe et al. (2009) for images showing the evolution of the lake)" Reference: Somos-Valenzuela, Marcelo, Daene C. McKinney, David R. Rounce, and Alton Byers (2014), *Changes in Imja Tsho in the Mt. Everest Region of Nepal*, The Cryosphere, 8, 1661-1671, 2014, doi:10.5194/tc-8-1661-2014

Comment 7:

Page 13032, lines 3-10: remedial works are mentioned here to reduce the GLOF hazard – but it looks like that he authors think only about the rapid, not controlled outburst of the lake to reduce the water level for 20 m. Whereas from the Discussion is clear that they know also about the slow, controlled water level drop.

Response to Comment 7:

Unfortunately, the text was not clear at this point. It has been revised in the manuscript to read:

"There are many impacts that might occur from a rapid uncontrolled GLOF from Imja Tsho that will be felt downstream, in particular there are several stretches of the main trekking trail from Namche Bazar to Lukla that run quite close to the river and would be washed away, as they were in the 1985 Dig Tsho GLOF (Ives, 1986; Vuichard and Zimmermann, 1986). In addition, some parts of villages along the trail have fields and houses near the river, and they may also be impacted. The feasibility of possible remedial actions at Imja Tsho to reduce the hazard to downstream communities was evaluated. One scenario that appears to have significant risk reduction potential is the slow, controlled lowering of the lake by 20 m."

Comment 8:

Page 13032, line 14: The "top of the moraine" is all the time the same – it is not wider or less wide because of the elevation of the water level, because it is a geomorphologic term connected with the moraine itself not with the presence or absence of water inside the moraine. On the other hand it is clear that the part of the moraine which is higher than the water table in the moraine cold be more or less wide. It is necessary to rewrite the sentence.

Response to Comment 8:

The reviewer is correct the top of the moraine won't change if the lake is lowered. What changes, it is the width of the moraine at the water level. Therefore the text from line 12 has been modified to read: "Lowering the lake by any amount will reduce the probability of GLOF occurrence for at least two reasons, the hydrostatic pressure on the moraine would be reduced and the west to east width of the moraine at the water level would be increased and more difficult to breach. Consequently, reducing the GLOF's occurrence probability would decrease the hazard level downstream."

Comment 9:

General remark: I expect that other papers which used HEC-RAS model (in different regions with GLOFs) will be mentioned or in the Introduction or in Discussion in order to know that authors know these papers.

Response to Comment 9:

Secction 4.1 of the paper discusses previous modeling of a potential GLOF from Imja Tsho. Especially the work of researchers from ICIMOD has been mentioned there in some detail. The following paragraph has been inserted at the beginning of Section 4.1:

"HEC-RAS has been used to simulate GLOFs in the Nepal Himalaya by several other researchers. Cenderelli and Wohl (2001) used one-dimensional steady flow HEC-RAS modeling to estimate peak discharges of the 1977 Nare and 1985 Dig Tsho GLOFs. Osti et al. (2009) modeled the 1998 GLOF at Tam Pohkari using HEC-RAS to perform one-dimensional, unsteady-flow calculations; however, the model could not be used to model the debris flow. They note that the GLOF was very strong and damaging, and the peak discharge was much higher than the results of the water-only computations.. Other models have been used to model GLOFs. Dwivedi (2007) modeled the 1998 Tam Pokhari GLOF using the SOBEK flood model (Alkema et al., 2004) and a 40 m resolution DEM. Several breaching scenarios were simulated, and eroded sediments were not considered in the model. Shrestha et al. (2013) modeled a potential debris-flow GLOF originating at Tsho Rolpa in the Rolwaling Valley of Nepal including the moraine breaching process due to an assumed seepage failure. Laboratory experiments were conducted to verify the model and good agreement with model results were obtained. Worni et al. (2012) who used the dynamic, erosion-based dam break model BASEMENT (Faeh et al., 2011) to model a debris-flow GLOF in the Argentinian Patagonia. BASEMENT is a tool for the analysis of breaching processes of non-cohesive earthen dam structures and water-sediment flows (Volz et al., 2010). Schneider et al. (2014) simulated the cascade of mass movement processes of an avalanche triggered GLOF from Lake 513 in the Cordillera Blanca of Peru by coupling different physically-based numerical models. Glacial lake dam overtopping hydrographs and water volumes were used as input for downstream debris flow modeling with RAMMS (Christen et al., 2010)."

References:

- Alkema, D., and Middelkoop, H.: The Influence of Floodplain Compartmentalization on Flood Risk within the Rhine-Meuse Delta. Natural Hazards 36: 125-145, 2005.
- Cenderelli D. A. and Wohl, E. E.: Peak discharge estimates of glacial-lake outburst floods and "normal" climatic floods in the Mount Everest region. Geomorphology 40: 57–90, 2001.
- Christen, M., Kowalski, J., and Bartelt, P.: RAMMS: numerical simulation of dense snow avalanches in three-dimensional terrain. Cold Regions Science and Technology 63, 1–14, 2010.

- Dwivedi, S.K.: Two Dimensional Simulation of a Glacial Lake Outburst Flood (A Case Study of Tam Pokhari Lake; Nepal Himalaya). M.S. Thesis, International Institute for Geoinformation Science and Earth Observation. Enshede, The Netherlands. February, 2007.
- Faeh, R., Mueller, R., Rousselot, P., Veprek, R., Vetsch, D., Volz, C., Vonwiller, L., Farshi, D.: BASEMENT – Basic Simulation Environment for Computation of Environmental Flow and Natural Hazard Simulation. VAW, ETH Zurich. http://www.basement.ethz.ch (Last accessed 13 February 2015). 2011..
- Osti, R., and Egashira, S.: Hydrodynamic characteristics of the Tam Pokhari Glacial Lake outburst flood in the Mt . Everest region, Nepal. Hydrol. Process. 23, 2943–2955, doi: 10.1002/hyp.7405, 2009.
- Schneider, D., Huggel, C., Cochachin, A., Guillén, S., and García, J. Mapping hazards from glacier lake outburst floods based on modelling of process cascades at Lake 513, Carhuaz, Peru. Adv. Geosci., 35, 145–155, doi:10.5194/adgeo-35-145-2014, 2014
- Shrestha, B.B, Nakagawa, H., Kawaike, K., Baba, Y. and Zhang, H.: Glacial hazards in the Rolwaling valley of Nepal and numerical approach to predict potential outburst flood from glacial lake. Landslides 10:299–313 DOI 10.1007/s10346-012-0327-7. 2013.
- Worni, R., Stoffel, M., Huggel C., Volz, C., Casteller, A., and Luckman B.: Analysis and dynamic modeling of a moraine failure and glacier lake outburst flood at Ventisquero Negro, Patagonian Andes (Argentina). Journal of Hydrology 444–445: 134–145. 2012.
- Volz, C., Rousselot, P., Vetsch, D., Mueller, R., Faeh, R., Boes, R.: Numerical modeling of dam breaching processes due to overtopping flow. In: Proc. 8th ICOLD European Club Symposium 2010, 22-23 September. Innsbruck, Austria, pp. 691–696. 2010.

T. Watanabe (Referee)

Specific Comment 1:

Page 13022, lines 16-18: In the expected outcome, the authors state that this is the first attempt to quantify the impact in downstream villages. This is true but this particular study examines only two villages among many others. For readers who are not familiar to local situations, it would be nice if the authors provide some geographical information on Dingboche and especially Phakding: their locations, relative height from the current river course to the arable land and houses with representative cross-sectional profiles of the villages or with photographs. Also for such readers, it would be nice if they state that Lukhla, a gateway to the Everest trekking area, can be excluded because of its high location from the current riverbed, so that discussion on the section between the lakeside and Phakding is appropriate.

Response to Specific Comment 1:

We agree and the following paragraph and two figures have been added to the manuscript.

"Dingboche is probably the most risk prone area from a potential Imja GLOF. The villages of Chukkung (~ 4 km) and Dingboche (~ 8 km) are the two nearest settlements from the lake. The former is located relatively off the Imja Khola (stream), so at less risk, whereas the latter is the largest settlement along the stream and it has extensive agricultural lands and buildings within 10-20 m elevation from the stream that will be flooded in the event of a GLOF unless flood prevention measures are taken. Two villages in the path of a potential GLOF from Imja Tsho have been the focus of the work reported here: Dingboche (27° 53.563' N, 86° 50.092' E, 4410 m) about 8 km downstream from the lake and Phakding (270 44.624' N, 86 o 42.767' E, 2569 m) about 33 km below Imja Tsho. Dingboche is a village of about 200 residents with an economy that depends on local agriculture and trekking and climbing tourism. Figure 2 shows the Imja Khola and the relative height from the river course to the arable land and houses (about 22 m above the river). About 34 km downstream of the lake outlet are low-lying portions of the village Phakding, which is a village of about 1500 residents with an economy that depends on local agriculture and trekking tourism. Most of the village is quite high above the river and is not at risk of damage from a GLOF. However, several farms and lodges are quite close to the river. Figure 3 shows the bridge crossing the Dudh Koshi and the relative height from the river course to the Star Lion lodge (about 13 m above the river). Lukla, a gateway to the Everest trekking area, can be excluded from consideration here because of its high location from the current riverbed, so that discussion on the section between the lake and Phakding is appropriate."



Figure 2. The village of Dingboche on the Imja Khola showing the river (right) and the relative height from the river course to the arable land and houses (about 22 m).



Figure 3. Bridge across the Dudh Koshi at the Star Lion Resort near the village of Phakding showing the bridge and the relative height from the river course to the arable land and houses (about 10 to 13 m).

Specific Comment 2:

Figures 4 and 8 would result in a great impact to the local residents when they access the figures. The impact could be too much for some of them. It will be extremely important for the authors to make an action to find an opportunity to explain about the results to the locals to avoid creating unnecessary 'mental hazards' at the earliest convenience, which, I do hope, the authors can understand because they are the persons who are leading the High Mountain Glacial Watershed Program (HMGWP) and the High Mountains Adaptation Partnership Program. This study can be a good example that is addressing a role of science that communicates with the locals. It is suggested that this aspect is added in a few lines in an adequate place such as a postscript.

Response to Specific Comment 2:

The authors appreciate this comment and are very well acquainted with the concerns of the local residents in the Khumbu area of Nepal regarding research into glacial lakes, especially Imja Tsho. Through the High Mountains Adaptation Partnership (HiMAP) program, the authors have made a concerted effort to communicate research findings to members of the local communities in over 14 meetings between 2011 and 2014. This has included meetings with the Khumbu Alpine Conservation Council (KACC) (Sep. 2011, May 2012, Sep. 2012, Sep. 2013, May 2014),

holding climate adaptation workshops in Phakding, Namche Bazar and Dingboche (Sep. 2012), meeting with religious leaders at the Tengboche and Pangboche Monasteries (May and Sep. 2012, Sep. 2013), and meetings with Dingboche community members (at Imja Tsho in Sep. 2011 and May 2012 and in Dingboche Nov. 2014). We understand that Figures 4 and 8 may have a great impact on local residents when they access the figures, but they have already been introduced to these results and the implications of them several times. The authors have taken actions to find opportunities to explain the results to the locals in order to avoid creating unnecessary 'mental hazards'. We believe that our work has demonstrated good practice in communicating science results to the local communities.

Specific Comment 3:

The order of citations in the whole text is not consistent: some are in alphabetical order, and the others are chronological.

Response to Specific comment 3:

Thank you for pointing this out. The manuscript has been revised to correct this; the citations are ordered according to the journal policy.

Specific Comment 4:

Caption of Figure 2: Between 'Dingboche' and 'under', add '(cross section shown in Fig. 4)'.

Response to Specific Comment 4:

We have included this in the caption of the figure.

S. Bajracharya (Referee)

General Comments:

This paper assessed the downstream inundation using a 2-dimensional debris flow model based on the 40m interval contour topographic maps. Some of the terraces along the river valley are at less than 20m height from the river bed. The inundation result in those terraces will be less realistic. It can be improved with the high accuracy DEM. The GLOF destructed terrace slope along the river valley in the high elevation region are more unstable due to rain/snow/wind erosion. The growth rate of vegetation is very slow in the high elevation region and once the slope has been disturbed and possibility of continuous erosion than the stabilization. The lesson should be learnt from the continuous damages on the river terraces along the downstream of Dig Tsho after the GLOF of 1985.

Response to General Comments:

We agree with the reviewer, the quality of the topography, in particular the resolution, is one of the main sources of error. This paper analyses the inundation extension from Imja Tsho to Dingboche using a high resolution DEM (5 m x 5 m grid cells produced according to the method of Lamsal et al. (2011)); therefore, the maps and cross sections more representative of the real conditions than the 40m contour representation downstream of Dingboche. In the upper portion, Imja Tsho to Dingboche, the quality of the terrain information is adequate for this analysis. This is not the case for the section from Dingboche to Phakding, where the inundation was modeled using coarser 40 m contour topography as indicated by the reviewer. For that reason we did not report the inundation extension in that region and reported only the shape of the hydrograph at Phakding calculated using the lower quality terrain data. That information is still of interest since it gives a first approximation of the travel time and peak discharge more than 20 km downstream of the lake.

Reference:

Lamsal, D., Sawagaki, T. and Watanabe, T.: Digital Terrain Modelling Using Corona and ALOS PRISM Data to Investigate the Distal Part of Imja glacier, Khumbu Himal, Nepal. J. Mt. Sci. 8: 390-402, 2011.

Specific Comments

Specific Comment 1:

Is lowering of lake level the only solution or have some other options to reduce the hazard and risk level of the downstream villages from the potential glof?

Response to Specific Comment 1:

Surely, lowering the level of the lake is not the only solution to reduce the dangerous lake risk, but it is the most practical, technical and economical. What are the variables that drive the hazard or the threat of lakes? Hanging glaciers, structure of the moraine, volume of the lake, seismic activity (not very well known) length and slope of the downstream valley, social vulnerability and some of these can produce triggering factors. In theory there are various solutions to reduce lake risk, but the one that has been applied and has given positive and practical results has been the reduction of lake volume by lowering the lake level. The major question is how much should

the volume be reduced? Modeling various scenarios is the best way to define the needed volume reduction in most dangerous lakes. At Tsho Rolpa after lowering the lake 3 m the final report says that to complete the risk reduction the lake should be drained at least 17 m more (Rana et al., 2000). Actually without a detailed analysis UNDP declared that 3 m lowering would reduce the risk, but what has been shown here is that this decision is not enough to reduce the risk significantly.

Reference:

Rana, B., Shrestha, A. B., Reynolds, J. M., Aryal, R., Pokhrel, A. P. and Budhathoki, K. P.: Hazard Assessment of the Lake Rolpa Glacier Lake and Ongoing Remediation Measures, J. of Nepal Geological Society 22: 563-570, 2000.

Specific Comment 2:

There is already lake lowering example of Tsho Rolpa in Nepal, which was supposed to reduce 20m lake level but reduced only 3m in 2000 and never attempted for further reduction of lake level. But there are very good examples from Raphstreng Tso and recently Thorthormi Tso lake lowering in Bhutan by manual excavation.

Response to Specific Comment 2:

According to our result, lowering Imja Tsho by 3m won't reduce significantly the risk, which is what already happened in Tsho Rolpa. So there is a great opportunity to avoid the same mistake; of course, we understand that due to budget limitations it may not be possible to lower the Imja Tsho more than 3m. Regarding the lake in Bhutan, it represents a great example of how local techniques and efforts can be used to solve problem of this magnitude. The solution needs to be planned according to the resources of the country if we want them to be sustainable.

Technical Corrections

Technical Correction 1:

Page 13021, line 23-25. "These conflicting classification are confusing and can be misleading to the general public and communities downstream, who are the stakeholders these studies are meant to assist." Could you please reflect your opinion about the classification of the lake?

Response to Technical Correction 1:

The purpose of this paper is not to attempt to classify the level of risk posed by Imja Tsho, since the Government of Nepal and the United Nations Development Programme have already made this characterization. Rather, our intent here is to analyze the potential risk reduction due to lowering the water level in Imja Tsho by different amounts including the often-stated 3m. The UNDP (2013) "ProDoc" and subsequent project documents state that lowering the lake level more than 3m will indeed reduce risk to downstream communities. However, no analysis of this statement exists in the literature or any other reports or documents. It is not advisable to spend such large sums of money and end up with a project implementation that may achieve almost no reduction of the risk due to the lake in its present condition or its condition 20 to 30 years in the future.

Reference:

UNDP-United Nations Development Programme: Community Based Glacier Lake Outburst and Flood Risk Reduction in Nepal. Project Document, UNDP Environmental Finance Services, Kathmandu, Nepal, 2013.

Technical Correction 2:

Page 13023, line 20-22, "34.1±1.08 million m3 of water could drain from the lake was if the lake surface elevation decreases 35m from 5010 to 4975m (the elevation of the valley floor below the lake)." Sakai et al., 2007 mentioned that the relative height of the foot of the left end moraine in relation to the lake surface level was only 30m. Lake level should not be drained below the surface level, please make it clear.

Response to Technical Correction 2:

Sakai et al. (2007) state: "Thus, were the left side of the end moraine or dead ice to melt or collapse, a GLOF would occur. And if the left side of the moraine and dead ice area were to completely collapse, the lake water up to 30m depth would flow away. The water volume reached 20.6×10^6 m³." In that paper, they do not provide any justification for choosing the value of 30m. They also show their benchmark BM7 at the base of the front face of the terminal moraine to be at an elevation of 4964m (Table 1, Sakai et al. (2007)) and the contour above that to be 4975m (Fig. 5, Sakai et al. (2007)). We have regularly measured the elevation of the valley floor below the lake at the face of the terminal moraine to be 4975m with handheld GPS instruments. In any case, the 35m potential depth of drainage seems reasonable.

Reference:

Sakai, A., Saito, M., Nishimura, K., Yamada, T., Iizuka, Y., Harada, K., Kobayashi, S., Fujita, K. and Gurung, C. B.: Topographical survey of end-moraine and dead ice area at the Imja Glacial Lake in 2001 and 2002. Bulletin of Glaciological Research, 24, 29-36, 2007.

Technical Correction 3:

Page 13024, line 2-4, "Other factors that may trigger a GLOF from Imja Lake include hydrostatic pressure or seismic effects causing a failure of the moraine dam." What about the torrential rainfall like as in 1993 and others in Nepal at Imja moraine and/or lake, which can damage the moraine and trigger a GLOF.

Response to Technical Correction 3:

We agree and have included excessive rainfall as another possible trigger for GLOF at Imja Tsho. Therefore the paragraph has been revised from lines 2 to 5 in page 13024, after "Somos-Valenzuela et al., 2013)" and now it reads:

"Other factors that may trigger a GLOF from Imja Tsho include excessive rain and potential blockage of the outlet that may be produced by ice that is calved at the glacier terminus."

Technical Correction 4:

Page 13025, line 9, "Table1 was taken from the bathymetric survey results of Somos- Valenzuela et al. (2014)". Mention here the year of bathymetric survey.

Response to Technical Correction 4:

The paragraph has been changed from lines 7 to 9 and now it reads:

"The value of Vw in Table 1 was taken from the 2012 bathymetric survey results of Somos-Valenzuela et al. (2014)."

Technical Correction 5:

Page 13031, line 15-17, "The reason for the differences here is most likely the use of the significantly smaller Imja Lake volume in the ICIMOD calculations due to the bathymetry used." Do you mean the discharge and flood arrival time scenario depends on the volume of the water?

Response to Technical Correction 5:

The interpretation of the reviewer is correct. Peak discharge and breaching generally are functions of the volume of the lake and similarly for the travel time, which becomes more dependent on the lake volume and less on the breach hydrograph as the inundation propagates downstream.

Technical Correction 6:

Page 13027, line 19-20. "Lowering the lake level by 3m does not resulting a significant change in the failure time and only a 13.8% decrease in the peak discharge".

Page 13034, line 17-21. "Inundation reducing scenarios were analyzed and an alternative under design, lowering the lake at least 3m, was found not to have significant flood reduction benefit. The results indicate that the lake needs to be lowered about 20 m in order to completely reduce the impacts that a GLOF could have at Dingboche and further downstream."

Page 13033, line 25-29. "An outlet channel was constructed at Tsho Rolpa and 3 m lowering was achieved; however, the design called for lowering the lake by 20 m which was never attempted because of funding limitations (Rana et al., 2000; Mool et al., 2001). Our results show that lowering Imja Lake 3 m would not lead to a significant inundation reduction downstream."

You had clearly mentioned that the Imja lake lowering by 3 m would not result to a significant inundation reduction downstream but the UNDP Imja Lake project is lowering the lake by 3m to achieve significant risk reduction downstream (UNDP 2013). This is contradiction in analysis and result. You are very much aware on the outlet construction at Tsho Rolpa as well.

Response to Technical Correction 6:

The UNDP Imja Lake project documents (UNDP 2013) state that the objective of the project is to reduce risk to downstream communities by reducing the lake level by "at least" 3m. This raises the question of how much lowering is required to achieve substantial risk reduction downstream. An additional question is what would be an acceptable level of risk downstream? It is the purpose of this paper to explore the possible levels of reduced inundation (and hence risk) due to different lake lowering levels. In personal communications with the UNDP staff, they have repeatedly stated that the 3m minimal threshold level is due to budgetary constraints.

Technical Correction 7:

You are very much aware of funding limitations to meet the design in lowering the lake level in Tsho Rolpa. The UNDP Imja Lake project is also repeating the same story as in Tsho Rolpa by reducing 3m lake level in Imja Tsho. Would you like to recommend any other options to prevail optimum risk reduction from potential GLOF in Himalaya?

Response to Technical Correction 7:

As we have stated in the paper, lowering the lake by about 20 m appears to provide some significant risk reduction. Our recommendation, at this time, would be to lower the lake to this level if possible. We are also concerned about the future condition of the lake and recent analysis of the lake expansion indicates that in about 15-20 years, the lake may expand to the point where avalanches of ice and debris from the surrounding high mountains could reach the eastern end of the lake and possibly create impulse waves that could approach, overtop and destroy portions of the terminal moraine and create a GLOF. Further study is needed to understand the future wave generation potential, but this is a major concern. To date we have not seen any indication that the lake lowering designs are considering the future condition of the lake. We are aware of the funding limitations so any effort to lower the level of the lake is welcome; however, it is important to keep in mind that a completely safe level won't be reached by lowering the lake only 3m. We would further recommend that the UNDP and Government of Nepal seek funding to complement the UNDP project funding from other governments or international institutions that could allow lowering the lake more than 3m.

Technical Correction 8:

Make lowercase for the initial of second and third word in:

Table 1. eg; Current Conditions - Current conditions Lake Lowering - Lake lowering

Table 2. Mean Prediction Error - Mean prediction error Uncertainty Band - Uncertainty band Breach Width - Breach width Failure Time – Failure time Peak Discharge – Peak discharge Failure Time – Failure time Similarly correct in table 3, 4 and 5 and legend of figures 2 to 8 and at axis if exist.

Response to Technical Correction 8:

The figures and tables have been revised and changed according to the comment.