Dear reviewer,

thank you for your comments. With all due respect, we can not agree with some of them, or find them inadequate in relation to the aims of the work (see our specific responses below). Nevertheless, we believe that this discussion will help to improve overall quality of the manuscript. We would like to stress, that the method is conceptually designed for assessment of high number of lakes with limited range of input data (based on remotely sensed data). Potentials for five Scenarios of GLOFs are assessed. Decision trees for each Scenario as well as determination of all thresholds provide instructive guide for repeated use. An essential part of our work is also the verification of presented method, with emphasis on the Cordillera Blanca. This verification, based on assessment of pre-flood conditions of lakes which produced GLOFs in past with those lakes which did not, showed fairly good functionality of presented method.

The subject of this paper is extremely topical and of significant interest especially with regard to the impact of climate change on high mountain environments such as the Cordillera Blanca, Peru. However, the paper submitted by Mssrs Emmer and Vilimek is serious flawed and requires substantial reworking before it can be considered for publication.

Generally, we would like to emphasise, that presented method is designed to provide repeatable methodological concept for identification hazardous glacial lakes with no need for field survey (based on remotely-sensed data). Thus, some simplification needed to be done. Nevertheless, we suppose, that we presented useful method for this purpose. Ongoing glacier retreat leads to the formation and evolution (changing hazard) of glacial lakes, which need to be assess to identify, assess and mitigate hazard duly.

Firstly, the concept of 'potential hazardousness' is extremely unhelpful and effectively meaningless. Either a glacial lake system poses a hazard, the scale of which can be ranked from minimal to severe or extreme, or it does not. There are long-standing and well-accepted definitions of 'hazard', 'risk' and 'vulnerability' that exist to aid understanding and for clarity; 'potential hazardousness' seems to blur many issues and just increases the vagueness associated with the associated arguments, as will be seen.

The term „potential hazardousness“ was used to describe “possibility of a sudden release of water following glacial lake dam failure or overtopping“, while “hazard“ is strictly defined as “probability, that particular threat occurs in given period of time“. Presented method do not calculate probability, thus term “hazard“ could not be used. In accordance with review by Dr. Martin Mergili, we will use term “susceptibility to GLOF” in next version of the manuscript.

On page 3, the authors describe a number of different ways that flood water is released, but it fails to recognise that in some cases, there is a combination and multiple methods may exist at a single lake over a period of time – Laguna 513 at Hualcán in the Cordillera is but one example. Separating the processes as a means of differentiating a series of scenarios is arbitrary and artificial with little physical basis.

It is clear, that GLOFs are highly complex processes, therefore some simplification had to be done. Five Scenarios of GLOFs are, nevertheless, based on mechanisms of GLOFs recorded and described within the Cordillera Blanca (e.g. Lliboutry et al., 1977; Zapata, 2002; Hubbard et al., 2005; Carey et al., 2012; Emmer and Vilímek, 2013; Emmer et al., 2014; Vilímek et al., 2014), thus they are not wholly "artificial". 2010 GLOF from lake No. 513 was caused by icefall from Mt. Hualcán into the lake, producing displacement wave, which overtopped the lake dam (Carey et al., 2012). This mechanism is in presented method defined as Scenario 1.

On page 3, the authors claim that Reynolds (2003) presented a method for assessing hazards "directly on the region of the Cordillera Blanca". This is incorrect. The methods apply to any glacierised environment.

Accepted. This will be edited in the next version of the manuscript. Generally, whole section 1.2 will be edited (see below, see two other reviews and responses in open discussion).

On page 4, in section 2, the authors raise what they call the "principle of regional focus" – making a claim that the glaciers in the Cordillera Blanca are a special regional case and that the causes and mechanisms of GLOFs in this region are somehow different to those elsewhere in the world. From having studied these processes from southern Patagonia to the high Himalayas, and especially the Cordillera Blanca, the glaciers behave no differently and the laws of physics apply equally everywhere. To make such a claim of regional difference is just not supportable.

We did not study behaviour of glaciers, but it was shown in our previous research (Emmer and Vilímek, 2013; Vilímek et al., 2014), that glacial lakes and also GLOFs within the region of the Cordillera Blanca has some specifics. These are connected to the share and representation of causes and mechanisms of GLOFs, implementation of remedial works on the dams … Presented method is constructed to account these specifics, thus is characterised as a regionally-focused. Of course, some of parameters and Scenarios (maybe most of them) are transferable to another regions, but we can not claim it without any investigation (see also our comment to review by anonymous reviewer). Method is also verificated for the lakes within the Cordillera Blanca.

On page 4, section 2 – this section introduces a number of so called principles and the discussion is written in such a way that it is thoroughly confusing and confused. It appears to be trying to separate out issues that are in fact inter-related. This whole section and the central themes underpinning this section are confused.

Accepted, this section will be edited in the next version of the manuscript, according to the specific comments in two other reviews.

In Section 2.1, p5, the authors make one of their five key scenarios the triggering of GLOFs by major earthquakes in the Cordillera Blanca. By checking catalogues of earthquakes with magnitudes #6 in the region from 1940 to 2012 (35 separate events), only two (which were related; on 31st May 1970) resulted in any outbursts from glacial lakes, as described by Lliboutry et al. (1977). Only Yanacocha-chica in Quebrada Putaca and a lake in Quebrada Huichajanca emptied, whereas the lake level in Safuna Alta dropped dramatically. Given the large number of glacial lakes in the region and the significant number of strong earthquakes, that so few floods have been triggered by earthquakes is hardly a justification for making this one of the five special scenarios.

It is unreasonable to disregard this cause, if it was recorded in the Cordillera Blanca. Five Scenarios defined in the method correspond with causes and mechanisms of GLOFs recorded in this region.

Also on p 5, line 5, the authors state that "we feel it is not meaningful to describe the overall potential hazardousness ... with the use of a single number". Why do they feel it is meaningful to create five different scenarios and then provide separate scoring for each? This is exemplified by Table 5 which is confusing and generally unuable.

Five detached results used in the methods provide more detailed information about potentials for GLOF following five defined mechanisms. They also allow to identify possible scenarios of GLOFs for particular lake. Table 5 shows results of assessment of pre-flood conditions of seven lakes, which produced 10 GLOFs in past.

On page 6, lines 10-13, the authors attempt to identify "the most likely scenario of the GLO for a particular lake". These scenarios are based on massive and unsupported assumptions.

These scenarios of GLOFs were described in literature and recorded within the Cordillera Blanca (e.g. Lliboutry et al., 1977; Zapata, 2002; Hubbard et al., 2005; Carey et al., 2012; Emmer and Vilímek, 2013; Emmer et al., 2014; Vilímek et al., 2014), therefore we suppose that they are not based on any "massive and unsupported assumptions".

On page 7, Section 2.3, the authors describe their five scenarios according to the trigger mechanisms, yet these scenarios do not take into account the likely behaviour of the lake water, and thus the form of breach processes and subsequent variations on flood hydrographs, all of which have enormous influence on the GLOF initiation process and subsequent flood dynamics.

Agreed, physical behaviour of lake water is not modelled in presented method and also flood hydrographs are not taken into the account, due to the data demands. This can be done with more detailed field survey as a case studies (e.g. Klimeš et al., 2014), but can not be used for method conceptually designed for assessment of high number of lakes with limited range of input data (presented method). This is already discussed in sections 4.1 and 4.3. Flood dynamics and downstream flood impacts are out of aims of this work.

In short, on pages 7 to 16, the various mathematical expressions have little relationship to actual physical processes or key components of the glacial lake system and appear to be based on guesses and assumptions, where the uncertainties are dressed up in mathematical equations. As an example, reference is made to Laguna 513 but the history of events that have occurred at this location is complex and the processes involved various, a fact missed by the authors of this paper. This in itself undermines their principal arguments.

Mathematical expressions are designed to simplistically describe five GLOFs Scenarios, by use of seventeen characteristics, which were chosen partly on the basis of previous researches (see Table 3) and partly on the basis of our own analysis (Emmer and Vilímek, 2013). These characteristics are also subordinate to the input data available from remote sensing. We refer to the 2010 GLOF from Lake No. 513 and its pre-flood condition (including implementation of remedial work), not to the complex history of events that have occurred at this location. As shown above, 2010 GLOF from lake No. 513 was undoubtedly caused by icefall from Mt. Hualcán into the lake, producing displacement wave, which overtopped the lake dam, despite the 20 m of freeboard (Carey et al., 2012). This does not undermine any principal argument presented in the method.

On page 10, the authors discuss at length the method of calculating lake volume from lake area based on empirical data. This in itself might be useful from a water resource perspective but it has little value in relation to GLOF volumes. The shape of a lake's containing basin and where the deepest parts are in relation to its dam are critical in relation to the behaviour of the lake water to an external trigger, of whatever type. Yet the volume of water that becomes involved in an outburst flood is typically less than the total lake volume, which often does not drain completely. So making a factor dependent upon lake volume is in itself misleading.

It is clear, that overall lake volume is maximal volume of water which is potentially available for GLOF, even if volume involve in GLOF is typically lower. Presented method is not designed to estimate flood volume, magnitude of flood or downstream impacts (see 4.1), but these are objectives of our case studies (e.g. Klimeš et al., 2014). We assume, that the lake volume calculation is not purposeless; it is required input for further calculations such as ratio of dam freeboard to the cube root of lake volume, or ratio of the upstream lake volume to downstream lake retention potential.

Generally agreed with the statement, that the shape of lake containing basin and relation of the deepest part of lake to its dam are characteristics, which are critical in water behaviour, BUT this can be used only for well-documented particular lakes (where bathymetry is known) and detailed studies, not for method conceptually designed for assessment of high number of lakes with limited range of input data (presented method). This is also discussed in sections 4.1 and 4.3.

There are also many variations in some of the input parameters in the various equations that the uncertainities involved render the arithmetic output meaningless. For example, let us the parameter Smax in equation (3). This is define by the authors as „the maximal slope of the moraine surrounding the lake“. Yet there are countless exampes of excessively steep slopes on moraines that have no role in the geomechanical failure of the lake's dam. Just finding the steepest bit somewhere along the moraine to plug into an equation is divorcing physical processes from the methods of assessment. This is fundamental flaw.

All assessed characteristics are clearly defined in Table 3. Parameter S_{Mmax} is defined as „Maximal slope of the moraine facing the assessed lake and measured from the lakeshore to the moraine crest“ and is used to estimate potential for landslide of moraine into the lake. Surely, there are differences in S_{Mmax} between different lakes and it is clear, that steeper moraine slopes are more susceptible to slope movements. To debunk, SMax is not stated as a parameter, which have role in the geomechanical failure of the lake's dam. Again, we we would like to stress, that presented method is conceptually designed for assessment of high number of lakes with limited range of input data (based on remote sensing).

Scenario 2 conflates the effect of two lakes. The hazard of the upstrem lake can be considered on its own merits rather than conflatinf two together which only copounds the uncertainities in the assessment of each, and results in another meaningless outputs.

Scenario 2 is designed to assess the possibility, that flood wave from a lake situated upstream will cause also flood from the lake situated downstream or not. Hazard of upstream situated lake is considered on its own merits (whole assessment procedure), not conflated.

The authors seem to introduce arbitrary factors when it suits, such on page 12m where they chose a factor of 0.05 on the vague premise of having analysed previous events (how?) and expert assessment (on what basis?). Simiparly, the authors introduce a power of 2 in equation 11 to emphasis what they say is a non-linear trend and also in equation 15 to demonstrate that piping does not occur.

Generally, we tried to provide repeatable methodological concept, therefore all thresholds needed to be determined. It is clear, that some are questionable, but it is still better than not to provide them at all (for detailed description of mentioned parameters see also specific comments in other two reviews). We would like to emphasize, that method verification proved good functionality of these equations, even if they are simplified.

The way the various parameters and equations have been constructed suggests a lack of understanding of the physical processes at play in this mountain environment and of the relationship between triggering processes and how the glacial lake systems can respond. The parameterisation in the form of relationships that are not based on key processes results in a complex and confusing set of processes that result in a variety of numbers, quoted to three significant figures, for a number of arbitrary scenarios that are over simplistic or unreasonable. It is clear that there is no meaningful physical basis for the resulting arithmetic outputs and as such the methods described are completely unhelpful and as such serve no useful purpose.

We cannot agree, presented method is useful for identification of hazardous glacial lakes, as presented in the verification section. Verification of the method showed, that assessment results of pre-flood conditions of lakes, which produced GLOF in history, are fairly distinguished from the assessment results of conditions of those lakes, which did not. This was the aim of the work and usage of presented method is clearly seen – to identify hazardous lakes from high number of lakes (total number of more than 2 000 lakes within the Cordillrea Blanca in these days), with no need for field survey, based on remotely-sensed data.

The authors also seem unaware of some of the literature concerning the Cordillera Blanca glaciers.

The list of references include 43 records, which are predominantly focused on the topic of GLOFs hazard assessment worldwide and especially to the glacial lakes within the Cordillera Blanca. From this point of view, we believe, that list of references is fairly complete. Actually, this work is not focused directly on glaciers of Cordillera Blanca, nevertheless, to satisfy reviewer's point, we will check and complete the list of references.

Yours Sincerely,

Adam Emmer and Vít Vilímek

email: aemmer@seznam.cz, vit.vilimek@natur.cuni.cz
Charles University in Prague, Faculty of Science,
Department of Physical Geography adn Geoecology,
Albertov 6, 128 43, Prague 2, Czech Republic

References:

Carey M, Huggel C, Bury J, Portocarrero C, Haeberli W (2012) An integrated socio-environmental framework for glacial hazard management and climate change adaptation: lessons from Lake 513, Cordillera Blanca, Peru. Climatic Change 112: 733-767.

Emmer A and Vilímek V (2013) Lake and breach hazard assessment for moraine-dammed lakes: an example from Cordillera Blanca, Peru. Natural Hazards and Earth System Sciences 13: 1551-1565.

Emmer A, Vilímek V, Klimeš J, and Cochachin A (2014) Glacier Retreat, Lakes Development and Associated Natural Hazards in Cordillera Blanca, Peru. In: Shan W et al. (eds) Landslides in Cold Regions in the Context of Climate Change, Environmental Science and Engineering. Switzerland: Springer, pp 231-252.

Hubbard B, Heald A, Reynolds JM, Quincey D, Richardson SD, Zapata ML, Santillán NP, and Hambrey MJ (2005) Impact of a rock avalanche on a moraine-dammed proglacial lake: Laguna Safuna Alta, Cordillera Blanca, Peru. Earth Surface Processes and Landforms 30: 1251-1264.

Klimeš J, Benešová M, Vilímek V, Bouška P, Cochachin AR (2013) The reconstruction of a glacial lake outburst flood using HEC-RAS and its significance for future hazard assessments: an example from Lake 513 in the Cordillera Blanca, Peru. Natural Hazards 71: 1617-1638.

Lliboutry L, Morales BA, Pautre A, and Schneider B (1977) Glaciological problems set by the control of dangerous lakes in Cordillera Blanca, Peru. I. Historical failures of moranic dams, their causes and prevention. Journal of Glaciology 18(79): 239-254.

Vilímek V, Emmer A, Huggel C, Schaub Y, Würmli S (2014) Database of glacial lake outburst floods (GLOFs) – IPL Project No. 179. Landslides 11(1): 161-165.

Zapata ML (2002) La dinamica glaciar en lagunas de la Cordillera Blanca. Acta Montana (ser. A Geodynamics) 19(123): 37-60.