Interactive comment on "Changes in Imja Tsho in the Mt. Everest region of Nepal" by M. A. Somos-Valenzuela et al.

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Comment 1. *In the first sentence of the paper (P2376, L16), Gardelle et al., GPC, 2011 is quoted to support the expansion of glacial lakes in Nepal since the 1960s. But Gardelle et al. 2011 only quantified lake area changes in the 90s and 2000s so a more appropriate reference needs to be given for the longer term evolution of glacial lakes.*

> **Response:** We agree. The sentence has been changed to read:
>
> "The rate of formation of glacial lakes in the Everest region of the Nepal Himalaya has been increasing since the early 1960s (Bolch et al. 2008; Watanabe et al. 2009; Bajracharya and Mool. 2009)"

Comment 2. *The same paper by Gardelle et al., GPC, 2011 also provides some estimates of the Imja lake area in October 2000 and October 2009 (see section 5.1). Those values may be added to your Figure 6.*

> **Response:** We agree. This information and other information about Imja Lake areas reported in the literature are listed in new Table 3 (below) in the paper and old Figure 6 has been deleted. With 8 different sets of data reported, it became too difficult to illustrate them all in a single figure and be able to identify each data set.

Table 3. Imja Tsho Area Expansion 1962-2012.

Year	Area (km^2)	Uncertainty (km^2)	Reference
1962	0.028		Bajracharya. et al. (2007)
1964	0.068		Lamsal et al. (2011)
1975	0.310		Bajracharya. et al. (2007)
1983	0.569		Bajracharya. et al. (2007)
1989	0.633		Bajracharya. et al. (2007)
1992	0.636		Bajracharya. et al. (2007)
1992	0.648	0.073	This study
2000	0.844	0.036	Fujita et al. (2009)
2000	0.775		Bajracharya. et al. (2007)
2000	0.766		Bolch et al. (2008)
2000	0.838	0.263	Gardelle et al. (2011)
2001	0.827	0.040	Fujita et al. (2009)
2001	0.824		Bajracharya. et al. (2007)
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2009	1.012		Watanabe et al. (2009)
2009	1.138	0.328	Gardelle et al. (2011)
2012	1.257	0.104	This study

Comment 3. *Selected mass balance for Imja-Lhotse Shar Glacier are given on page 2377. Additional mass balance estimates for the 2000s from Bolch et al., TC, 2011, Nuimura et al., JOG, 2012 and Gardelle et al., TC, 2013 are listed in Table 5 of Gardelle et al, TC, 2013. They could be added to the paper. On this matter, the authors could note that their bathymetric survey will also help also to refine the mass balance estimate of this glacier because it will improve the quantification of the aqueous losses. Also an important side product of their effort.*

> **Response:** We agree. We have added these values to the paper and revised the text to read:
>
> "Imja-Lhotse Shar glacier is located in the Imja Khola watershed in the Khumbu region (27.9° N, 86.9° E), about 9 km south of the summit of Mt. Everest. It is comprised of the Lhotse Shar glacier to the north and the Imja glacier to the east. The Amphu glacier appears to no longer contribute to the Imja-Lhotse Shar glacier. Bolch et al. (2011) studied the mass change for ten glaciers in the Khumbu region south and west of Mt. Everest, and found that the Imja-Lhotse Shar glacier exhibited the largest loss rate in the

Khumbu region, -0.5±0.09 m.w.e. yr^{-1} (meter water equivalent per year) for the period 1970-2007. Nuimura et al. (2012) also report significant surface lowering of the glaciers of this area, including –0.81±0.22 m.w.e. yr^{-1} (1992-2008) and −0.93±0.60 mw.e. yr^{-1} (2000–2008) for the Imja-Lhotse Shar glacier. Gardelle et al (2013) reported −0.70±0.52 mw.e. yr^{-1} (1999–2011), Bolch et al. (2011) reported −1.45±0.52 mw.e. yr^{-1} (2002–2007). The bathymetric survey reported here will help to refine the mass balance estimate of this glacier because it can be used to improve the quantification of the aqueous losses.
”

Comment 4. *The bathymetric survey will also help also to refine the mass balance estimate of this glacier because it will improve the quantification of the aqueous losses*

Response: We agree. This comment has been incorporated into the paper. See the response to Comment 3 above.

Comments on
Title: Changes in Imja Tsho in the Mt. Everest region of Nepal Author: M. A. Somos-Valenzuela, D. C. McKinney, D. R. Rounce, and A. C. Byers
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<General comments>

This paper reported that the lake depth measurement using sonar at the Imja Glacial Lake and thickness measurement using ground penetrating radar at the Imja-Lhotse Shar Glacier. They compared their results with past measured data at the lake. The purpose is simple and clear, but, several information are not enough to analyze.

The interpolation for data blank area looks nice in Fig.4. But, authors should describe why the result at the Tasman glacier can be applied to the Imja Glacial Lake.

> **Response:** Please see the response to Comment 3 below.

<Specific comments>

Comment 1. 2378 L26 1962 -> 1992

> **Response:** We agree. The text has been changed to read:
>
> "In 1992, measurements were taken at 61 points…"

Comment 2. 2380 L4-6 The sonar has GPS system? There is no information on the horizontal accuracy of the instrument, sonar. Further, the explanation on the sensor of sonar is not enough.

> **Response:** We agree. Yes, the sonar instrument has a GPS system integrated with it. The text has been modified to include:
>
> "Previous bathymetric surveys of Imja Tsho were conducted in 1992 (Yamada and Sharma, 1993) and 2002 (Sakai et al., 2003; Fujita et al., 2009). In 1992, measurements were taken at 61 points around the lake through holes drilled in the ice using a weighted line. In 2002, measurements were made at 80 uniformly spaced points on the lake using a weighted line. We conducted a bathymetric survey of Imja Tsho between September 22 and 24, 2012 using a Biosonic Habitat EchoSounder MX sonar unit mounted on an inflatable raft. The BioSonics MX Ecosounder (BioSonics, 2012) unit has an accuracy of 1.7cm +/- 0.2% of depth accuracy, 0-100m depth range, single frequency (204.8 kHz) transducer with 8.5 degree conical beam angle, and integrated DGPS with < 3m positional accuracy (Garmin, 2009). Several transects were made around the lake with the sonar unit measuring the depth (Figure 2).
> "

References:
Biosonics, Inc. MX Series Specifications and Features, Seattle Washington 2012. http://www.biosonicsinc.com/product-mx-habitat-echosounder.asp#specsheet <accessed 16 July 2012>

Garmin (2009), GPS 15xH/15xL Technical Specifications, 190-00266-03 Rev. A, Garmin International, Inc. Olathe, Kansas USA December, 2009

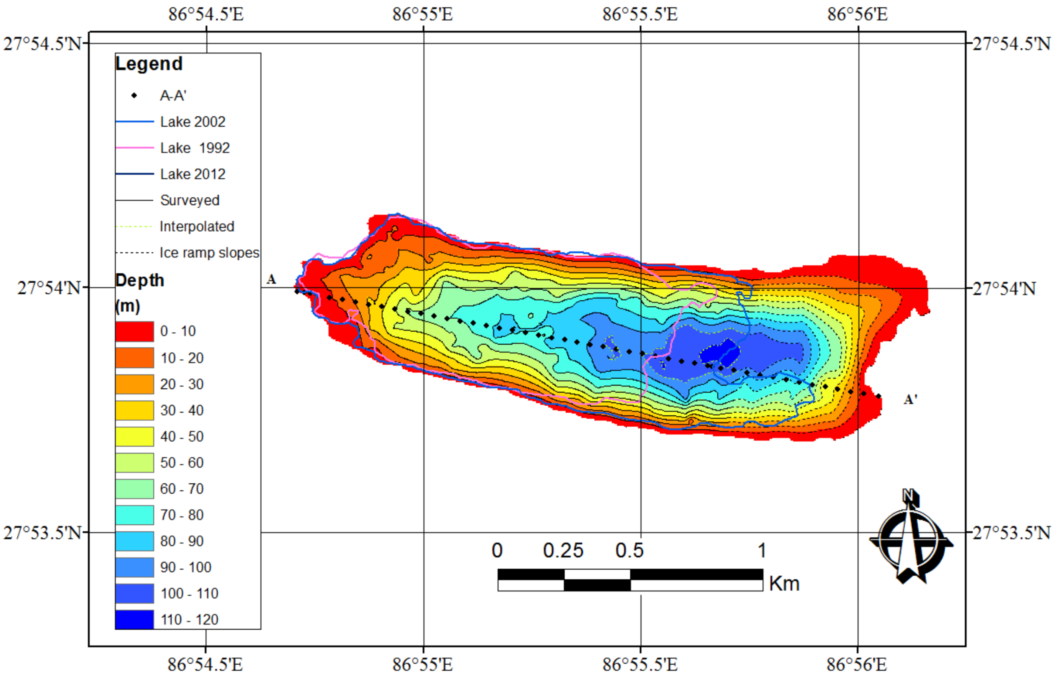
Comment 3. 2379 L17-20 'To fill .....until the measured points are reached.' There is no robust reason here. There are a lot of case to satisfy the condition of slope, which was reported by Robertson et al. (2012). This condition is one of the case to satisfy the conditions (Robertson et al., 2012). Further, authors should write why the result at the Tasman glacier (Robertson et al. (2012)) can be applied to the Imja Glacial Lake. Fortunately, I have depth data in Fig.4 in 1992 and 2002 (along with longitudinal cross section of the lake). So, I have calculated the slope in front of the glacier terminus at Imja Glacial Lake in 1992, 2002. The maximum slope was larger than 30 degree (Figure 1), which is the maximum degree of your assumption. The degree of slope in front of the glacier terminus is important information to judge whether the bottom ice is covered with debris layer (gentle) or expose (steep) (if there is ice at the lake bottom). Those conditions would affect on the calving process. So, please treat carefully.

Response: We agree with this comment and are grateful for the information that the reviewer generated in previous work and provided to us. The level of knowledge of ice ramps in glacial lakes is limited, so it is difficult to determine ramp gradients exactly without detailed bathymetric information. Rather than using the slopes from Robertson et al. (2012), that are more applicable to the Tasman glacier area, the slopes have been changed to resemble the slopes measured at Imja Glacial Lake in 1992 and 2002 by Sakai and others. Figure 3 below shows a line following the 1992 and 2002 longitudinal transects from the western shoreline of the lake to the eastern shoreline reported by Sakai et al. (2005). They found lake bottom slopes near the eastern shoreline in 1992 to be 39 degrees in the first 100 m from the glacier and 12 degrees in the next 200 m; in 2002 the slopes were found to be 32 degrees in the first 50 m, 20 degrees in the next 150 m and 12 degrees in the next 200 m (Sakai et al. 2005, Fig. 6, p. 77). In order to introduce this sloped behavior into the estimation of the lake bottom in the iceberg obstructed area of 2012 and to take account of the uncertainty in the bottom slope, minimum and maximum slopes of the lake floor in front of the glacier terminus were used to approximate bounds for the lake volume in 2012. The maximum slopes were 40 degrees for the first 100 meters from the shoreline, 20 degrees for the next 150 meters, and 5 degrees for the last 150 meters, while the minimum slopes were 20 degrees, 10 degrees, and 2 degrees, respectively. The slopes found by Sakai et al. (2005) are within these bounds. Figure 4 has been revised to show the data from the 2002 and 2012 bathymetric surveys. The 1992 survey was omitted because we do not have those data and had previously only approximated the values from the graphs in Sakai et al. (2005).

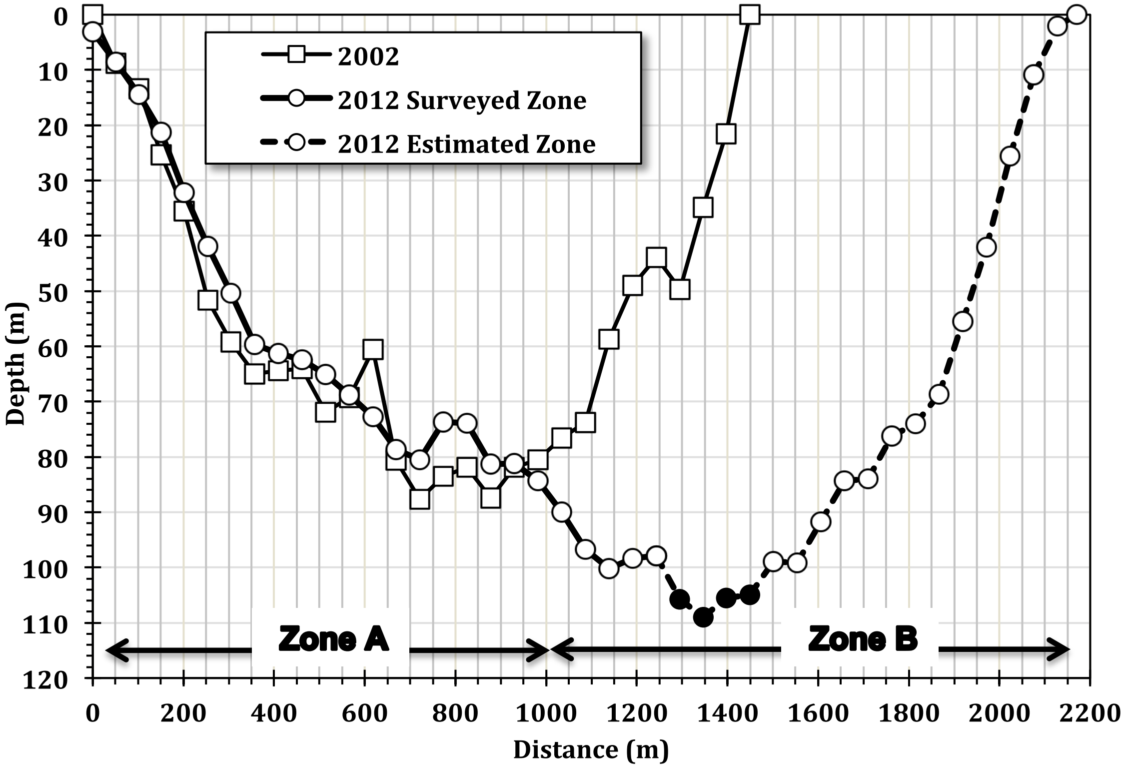
The text of the paper has been revised to read:

"During the survey, large icebergs blocked access to the eastern end of the lake.

Robertson et al. (2012) found that ice ramps at the glacier end of glacial lakes tend to have slopes between 11 and 30 degrees and exhibit subaqueous calving. The level of knowledge of ice ramps in glacial lakes is limited, so it is difficult to determine ramp gradients exactly without detailed bathymetric information. Rather than using the slopes from Robertson et al. (2012), that are more applicable to the Tasman glacier area, the slopes have been changed to resemble the slopes measured at Imja Tsho in 1992 and 2002 by Sakai et al. (2005). Figure 3 shows a line following the 1992 and 2002 longitudinal transect from the western shoreline of the lake to the eastern shoreline reported by Sakai et al. (2005). They found lake bottom slopes near the eastern shoreline in 1992 to be 39 degrees in the first 100 m from the glacier and 12 degrees in the next 200 m; in 2002 the slopes were found to be 32 degrees in the first 50 m, 20 degrees in the next 150 m and 12 degrees in the next 200 m (Sakai et al. 2005, Fig. 6, p. 77). In order to introduce this sloped behavior into the estimation of the lake bottom in the iceberg obstructed area of 2012 and to take account of the uncertainty in the bottom slope, minimum and maximum slopes of the lake floor in front of the glacier terminus were used to approximate bounds for the lake volume in 2012. The maximum slopes were 40 degrees for the first 100 meters from the shoreline, 20 degrees for the next 150 meters, and 5 degrees for the last 150 meters, while the minimum slopes were 20 degrees, 10 degrees, and 2 degrees, respectively. The slopes found by Sakai et al. (2005) are within these bounds. Figure 5 has been revised to show the data from the 2002 and 2012 bathymetric surveys."



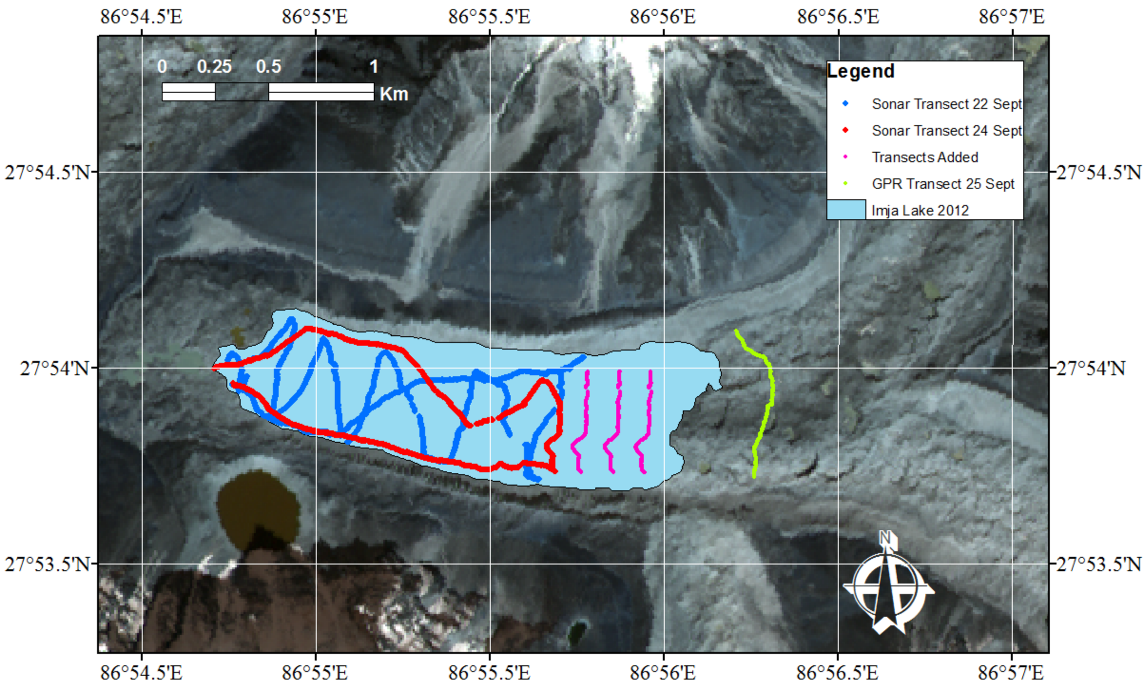
Paper Figure 3 (revised). Bathymetric survey results from Imja Tsho in September 2012.



Paper Figure 5 (revised). Cross-section A-A' of the 2012 bathymetric survey for Imja Tsho compared to the 2002 survey. The solid indicates surveyed points and dashed line indicates estimated points. The filled circle markers indicate points deeper than 100 m where interpolation was used.

Comment 4. 2379 L21-22 Authors should show the location of 'Three transects' in Fig. 3 or other detail figure.

> **Response:** Figure 2 in the paper has been modified to show the 3 transects used for calculating the water depth in the areas not accessible during the 2012 bathymetry survey do to dense ice coverage.



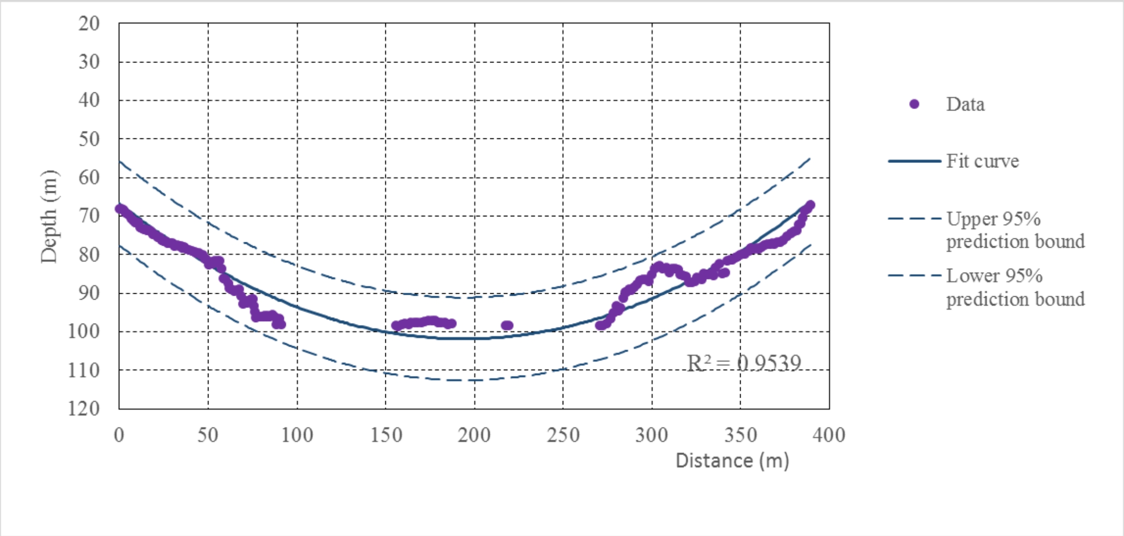
Paper Figure 2 (revised). Sonar bathymetric survey transects at Imja Tsho September 22 (red) and 24 (blue), the transects used to interpolate missing values (pink), and the GPR transect at Imja-Lhotse Shar glacier September 25 (green). The background is an ALOS image from 2008.

Comment 5. 3280 L5 ' For points in areas deeper than 100m that were interpolated, maximum and minimum depth values were calculated on 5m raster files,' There is no explanation on the maximum and minimum depth at the interpolated area. Those max and min were calculated from the error of sonar ?

Response: Yes, this point was not clear in the original document and the interpolation error was omitted. The maximum and minimum values were based on the sonar instrument's error (1.7 cm ± 0.2%*depth). The sonar instrument error applies to every point in the bathymetric survey. In the areas deeper than 100 m the error is higher due to the interpolation calculations, and this error must be added to the instrument error. Quadratic interpolating functions were fit to the points of the 4 transects that have missing data (Figure 2); for points deeper than 100 m, interpolated values and 95% prediction bounds were calculated. The bounds were used to estimate maximum and minimum values associated with each interpolated value. Figure R1 below shows this procedure for one transect as an example of the results. Interpolated values less than 100 m were omitted, since points shallower than 100 m have a measured value. Including the interpolation error along with the sonar error increases the total error of the calculation. This, in turn, increases the standard deviation of the calculated volume and the maximum depth error bounds. The new values for the volume, average depth and maximum depth are 61.7 ±7.4 million m^3, 48.0±5.8 m, and 116.3 ±5.2 m, respectively. An updated Table 1 from the paper is included below.

The text of the paper has been revised to read:

"The uncertainty of the lake volume calculation is estimated using a range of depth for each point. In the areas where we were able to measure the depth of the lake we could directly calculate the maximum and minimum values using the error of sonar equipment (1.7 cm ± 0.2%*depth). The sonar instrument error applies to every point in the bathymetric survey. In the areas deeper than 100 m, out of the sonar instrument range, the error is higher due to the interpolation calculations, and this error must be added to the instrument error. Quadratic interpolating functions were fit to the points of the 4 transects that have missing data (Figure 2); for points deeper than 100 m, interpolated values and 95% prediction bounds were calculated. The bounds were used to estimate maximum and minimum values associated with each interpolated value. Interpolated values less than 100 m were omitted, since the sonar instrument measured the depth at these points. This results in a cloud of points that cover the measured part of the lake and each point has an associated maximum and minimum value. The points were interpolated to generate 5 m resolution maximum and minimum depth raster files, thus providing two values for each 25 m^2. We assume that the depth in each cell follows a uniform probability distribution (USACE, 2003), which means that all the points within that range, maximum and minimum depth included, have the same probability of being the actual depth of the cell. In order to calculate the volume of the lake we used a Monte Carlo simulation with 2000 samples, which allows us to include the uncertainty in our measurement and assumptions; and calculate the expected value and standard deviation of the water volume."



Response Figure R1. Example of interpolations for areas deeper than 100 m. Solid line is the interpolation function and the dashed lines represent the 95% prediction bounds.

Paper Table 2 (formerly Table 1). Comparison of Imja Tsho 2012 Bathymetric Survey Results with Previous Studies. The 2012 volume and average depth uncertainty are 95% confidence bounds from the Monte Carlo sampling result. Maximum depth uncertainty is calculated from the 95% prediction bounds.

Study	No. of points	Volume (10^6 m^3)	Ave. Depth (m)	Max. Depth (m)
1992 (Yamada and Sharma; 1993)	61	28.0	47.0	98.5
2002 (Sakai et al.,; 2003)	80	35.8±0.7	41.6	90.5
2012 (This study)	10,020	61.7±3.7	48.0±2.9	116.3±5.2

2.1 Bathymetric survey

Comment 6. Method on the interpolation at the data blank area (ice berg blocked area) is written in this section. In order to interpolate, the shoreline has significant role. Information on the location adjustment between the site of sonar data and shoreline data is necessary here. Are there some benchmarks near the observed site?

> **Response:** The NDWI lake delineation using a Landsat image for 2012 was used to define the shoreline in the calculations (see Figure 5 in original paper). The Landsat images all had an image-to-image registration accuracy of 7.3 m. The absolute geodetic accuracy is estimated to be ~80 m. When using NDWI we have a maximum error of ±15m for each pixel. With respect to benchmarks near the observed site, there aren't any that we could use.

Comment 7. There is no description on the shoreline in this section. Lake area calculation section should locate before this section.

> **Response:** The Lake area calculation section has been moved to an earlier position in the paper. This has greatly improved the overall paper.

Comment 8. 2381 L17-23 In order to prevent miss-classification between debris-covered iceberg and debris-covered glacier ice, I recommend to compare with other images taken in 2012.

> **Response:** The NDWI delineated shoreline was used in the calculations. ASTER imagery is rather scarce during 2012 over Imja Tsho, so it is difficult to find good images for comparison. Google Earth also does not provide any other imagery around 2012 that would be useful. We have looked at the panchromatic band (Band 8) of Landsat 7, which has a 15m resolution. This band more clearly shows the presence of debris covered icebergs, which was found to agree well with the results of this study. Furthermore, the NDWI delineated shoreline agreed well with our observations of the shoreline in the field.

2.3 Calving retreat of Imja-Lhotse Shar Glacier

Comment 9. Calving rate is defined the mechanical loss of ice (ice separation) from glaciers. Here, authors analyzed expansion rate of glacial lake, not calving rate. If glacier ice is flowing, calving rate should include not only expansion rate of the lake but also glacier ice flow speed at the terminus.

> **Response:** Imja-Lhotse Shar glacier is stagnant at the glacier lake/ glacier interface (Quincey et al., 2007). Therefore, calving rate can be used since we were looking at the expansion only of the interface, i.e., the easternmost cell in each row. However, the reviewer is correct to suggest more precise terminology be used and the terminology was incorrectly used. The term "calving rate" has been changed to "expansion rate" throughout the paper.

Comment 10. Fig.3 The interpolated area and estimated zone (deeper than 100 m) should be hatched or the contour should be drawn by dotted line.

> **Response:** We agree. The figure has been updated considering the comment from the reviewer (See Comment 3 Paper Figure 3).

Comment 11. Fig.4 Estimated zone should be drawn by dotted line.

> **Response:** We agree. The figure has been updated based on the comment from the reviewer and the interpolated area (see Comment 3 Paper Figure 3).

Comment 12. 2383 L15 'Elevation within the 100-contour' => This description may be misunderstood. Area with deeper than 100 m would be appropriate.

> **Response:** We agree. The paper has been modified and the sentence now reads:
>
> "Areas deeper than 100 m were interpolated from the surrounding values as described below."

3.1 Bathymetric survey

Comment 13. Figure 4 can be depicted by assuming that the lake surface has not changed since 1992.
Authors have to mention the reason of the assumption.

> **Response:** Figure 4 has been changed to Figure 5 in the revised paper. Figure 5 shows the 2012 bathymetric survey results along section A-A' from Figure 3 along with those of the 2002 survey (Sakai et al., 2003, Fig. 4, p. 559), indicating an eastward expansion of the lake, rapid retreat of the glacier ice cliff and the subaqueous melting that has taken place. The data from the 2002 survey (location and depth) were provided to us by the authors (K. Fujita pers. communication 14 July 2014), and can be depicted in Figure 5 by assuming that the lake surface has not changed since 2002. This assumption is reasonable as various studies have shown that the level of the lake has not changed significantly since 2002 (Sakai et al.,2007; Lamsal et al., 2011; Fujita et al., 2009). Sakai et al. (2007)

observed a lake level of 5009 m in 2001. Lamsal et al. (2011) report no lake level change between 2006 and 2009. Fujita et al. (2009) note insignificant changes in the downstream shorelines of Imja Tsho during the 2000s, and that field surveys in 2001 and 2007 showed an unchanged lake level (within 0.2 m in height) during that period.

The paper has been modified to read:

"Figure 5 shows the 2012 bathymetric survey results along section A-A' from Figure 3 along with those of the 2002 survey (Sakai et al., 2003, Fig. 4, p. 559), indicating an eastward expansion of the lake, rapid retreat of the glacier ice cliff and the subaqueous melting that has taken place. The data from the 2002 survey (location and depth) were provided to us by the authors (K. Fujita pers. communication 14 July 2014) and can be depicted in Figure 5 by assuming that the lake surface has not changed since 2002. This assumption is reasonable as various studies have shown that the level of the lake has not changed significantly since 2002 (Sakai et al., 2007; Lamsal et al., 2011; Fujita et al., 2009)."

Comment 14. Table 1 The error of maximum depth 0.25 m in Table 1 would be induced from the instrument. If the maximum depth was measured by sonar, it is OK. But, actual maximum depth could not measured since the measurement range was less than 100 m. The error should be larger. Please, revise the maximum depth in 2012 in the text.

Response: The revised calculations and errors using both the sonar and interpolation error are reported in the table as mentioned in the response to a Comment 5 above.

Comment 15. Fig. 6 I can not find Yamada and Sharma (1993) data (rhombic mark) in the figure.

Response: We agree. This information and other information about Imja Lake areas reported in the literature are listed in new Table 3 in the paper and old Figure 6 has been deleted. With 8 different sets of data reported, it became too difficult to illustrate them all in a single figure and be able to identify each data set.

Paper Table 3. Imja Tsho Area Expansion 1962-2012.

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Comment 1. Although Sakai et al. (2007) estimated the potential drainage water in case of complete collapse of damming moraine, the assumption of "complete collapse" has to be discussed in detail because Imja Tsho is dammed by a wide moraine (> 500 m). Fujita et al. (2013) evaluated probability of outburst using remotely sensed digital elevation models on pre/post-GLOF images for five glacial lakes along the Himalayas. They found a critical angle of 10 degree between lake surface and outer terrain on the GLOF experienced lakes. It means that if damming moraine is wide enough or height difference is little enough, such lake will not cause a GLOF.

The estimation made by Sakai et al. (2007) and by this study is the maximum one. Although this kind of value is meaningful as a "rough estimation" when no other information available, at least probability of the assumption of "complete collapse" has to be discussed together with recent studies.

In addition, when one evaluates the volume, relative height between lake surface and base of moraine have to be precisely measured. However, no information is given in the manuscript in terms of topography around the lake.

Sakai et al. (2003) is an extended abstract of a conference. Sakai et al. (2007) provided more detailed analyses and discussions not only on bathymetry but also topography of damming moraine.

References

Sakai A, Saito M, Nishimura K, Yamada T, Iizuka Y, Harada K, Kobayashi S, Fujita K, Gurung CB (2007) 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. http://www.seppyo.org/bgr/pdf/24/BGR24p29.pdf

Fujita K, Sakai A, Takenaka S, Nuimura T, Surazakov AB, Sawagaki T, Yamanokuchi T (2013) Potential flood volume of Himalayan glacial lakes. Natural Hazards and Earth System Sciences, 13(7), 1827-1839. doi:10.5194/nhess-13-1827-2013. http://www.nat-hazards-earth-syst-sci.net/13/1827/2013/nhess-13-1827-2013.html

> **Response:** Fujita et al. (2013) proposed an index method for characterizing Potential Flood Volume (PFV) from glacial lakes in the Himalaya. The method is based on the depression angle between the lake water surface and any point within 1 km downstream. The depression

angle is surrogate for the width-to-height ratio of the damming moraine when that information is difficult to obtain. The potential lowering height (Hp, m) is the level that the lake must be lowered to so that the depression angle will be 10 degrees. The PFV = min[Hp; Dm]*A, where Dm is the mean depth (m) and A is the area (km^2) of the lake, respectively. One of the difficulties in applying Fujita's method at Imja Tsho is the definition of the point on the lake shoreline from which to start the calculation. If we consider three starting points for the PFV calculations: the western end of the main lake; midway from the main lake to the end of the outlet; and the end of the outlet.

Paper Table 5 (below) shows the results of these calculations for Imja Tsho. In these calculations, we have assumed the elevation of the lake and outlet are 5010 m and the downstream point is located at the place where the lake outlet stream enters the valley below the moraine at 4975 m. If the starting location is at the end of the lake outlet, then there is a PFV of over 11.3 million m^3, but starting the calculation from the other locations results in a PFV of zero. Certainly, the first case is a maximum one and can only occur if there is a complete collapse of the moraine. Fujita et al. (2013) imply that lowering the lake level to the point where the depression angle is less than 10 degrees may reduce this risk, which would require lowering the lake 9 m and removing of 11.3 million m^3 of water from the lake. This would represent a minimum level of lake lowering, since the PFV does not consider the condition of the moraine or possible breach triggering mechanisms. It is possible that the end of outlet complex should not be used in the calculations because it does not properly take into account the width of the moraine.

This level of potential drainage water is a rough estimate and would require a complete collapse of damming moraine, which may be unlikely since Imja Tsho is dammed by a wide moraine (> 500 m). Fujita et al. (2013) note that for Himalayan glacial lakes, if the damming moraine is wide enough or the height difference between the lake surface and the downstream valley is small enough, such a lake is unlikely to cause a GLOF. The relative height between lake surface and the base of moraine is not precisely known by land survey techniques. However, others have discussed the topography around the lake. The lake surface has lowered gradually over the past three decades (Lamsal et al. 2011) to a stable level of 5009 – 5010 m and the lake surface elevation is generally acknowledged to have been stable at about 5010 m for over a decade (Fujita et al. 2009; Lamsal et al. 2011).

Fujita et al. (2013) calculated a PFV of zero for Imja Tsho (because Hp = 0 < Dm), indicating that it that is reasonably safe at that time. They note that future lowering of the moraine dam may possibly result in future changes to the lakeshore downstream (Fujita et al., 2009); therefore, continuous monitoring of such large-scale lakes is required. Thus, understanding the bathymetry of these large glacial lakes is very important. We have witnessed downstream expansion, albeit slowly, in the southwestern part of the lake, where a small peninsula has disappeared over the past 3-5 years. This is a study on the bathymetry and concerning the risk of failure of the moraine is beyond the scope of the paper.

Sakai et al. (2003) and (2005) are conference proceedings and that Sakai et al. (2007) is a published journal paper. However, some information contained in the 2003 and 2005 papers is not included in the 2007 paper and we have used that information here, as have several other authors.

The text of the paper has been revised to read:

"Figure 6 shows the resulting drainage volume for various lake elevations. The maximum amount of water that could be released from the lake is 34.1±0.54 million m^3, if the lake surface elevation decreases from 5010 m to 4975 m (the elevation of the valley floor below the lake). In a previous (2002) estimate, this volume was 20.6 million m^3 (Sakai et al., 2007). The 2012 estimate is 40.5% larger than the 2002 value. This level of potential drainage water is a rough estimate and would require a complete collapse of damming moraine, which may be unlikely since Imja Tsho is dammed by a wide moraine (> 500 m). Fujita et al. (2013) note that for Himalayan glacial lakes, if the damming moraine is wide enough or the height difference between the lake surface and the downstream valley is small enough, such a lake is unlikely to cause a GLOF. The relative height between lake surface and the base of moraine is not precisely known by land survey techniques. However, others have discussed the topography around the lake. The lake surface has lowered gradually over the past three decades (Lamsal et al., 2011) to a stable level of 5009 – 5010 m and the lake surface elevation is generally acknowledged to have been stable at about 5010 m for over a decade (Fujita et al., 2009; Lamsal et al., 2011).

Fujita et al. (2013) proposed an index method for characterizing Potential Flood Volume (*PFV*) from glacial lakes in the Himalaya. The method is based on the depression angle between the lake water surface and any point within 1 km downstream. The potential lowering height (H_p, m) is the level that the lake must be lowered to so that the depression angle will be 10 degrees. *PFV* is defined as

$$PFV = \text{minimum}[H_p; D_m]*A \qquad (1)$$

where H_p is the potential lowering height, D_m is the mean depth (m) and A is the area (km^2) of the lake, respectively. One of the difficulties in applying this method at Imja Tsho is defining the point of the lake from which to start the calculation. We considered three starting points for the *PFV* calculations: the western end of the main lake; midway from the main lake to the end of the outlet; and the end of the outlet (Table 5). We assumed the elevation of the lake and outlet are 5010 m and the downstream point is located where the outlet stream enters the valley below the moraine at 4975 m. If the starting location is at the end of the lake outlet, then PFV = 11.3 million m^3, but starting from the other locations results in a *PFV* = 0. Certainly, the first case is a maximum one and can only occur is there is a complete collapse of the moraine. Fujita et al. (2013) imply that lowering the lake level to the point where the depression angle is less than 10 degrees may reduce this risk, which would require lowering the lake 9 m and removing of 11.3 million m^3 of water from the lake. This would represent a minimum level of lake lowering, since the PFV does not consider the condition of the moraine or possible breach triggering mechanisms. It is possible that the end of outlet complex should not be used in the calculations because it does not properly take into account the width of the moraine. Fujita et al. (2013) calculated a PFV of zero for Imja Tsho (because Hp = 0 < Dm), indicating that it that is reasonably safe at that time. They note that future lowering of the moraine dam may possibly result in future changes to the lakeshore downstream (Fujita et al., 2009); therefore, continuous monitoring of such large-scale lakes is required. Thus, understanding the bathymetry of these large glacial lakes is very important."

Paper Table 5. PFV Calculations for Imja Tsho Considering Three Starting Points on the Lake or Outlet.

	Calculation starting location			
	Lake	Outlet middle	Outlet end	Reduce to 10 deg
Distance (m)	641	364	150	150
Height (m)	35	35	35	26
Depression Angle (degrees)	3.1	5.5	13.5	10.0
A (km^2)				1.257
Hp (m)				9
PFV (million m^3)				11.3

Interactive comment on "Changes in Imja Tsho in the Mt. Everest region of Nepal" by M. A. Somos-Valenzuela et al.

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A few tiny points re English language editing:

Comment a) Page 2379, lines 27-29. The word "uncertainty" is used four times in one sentence. This is not acceptable.

> **Response:** We agree and have revised the text to read
>
> "In calculating the uncertainty associated with this volume, we considered the error in the depth measurements, and in the slope of the ice ramp, but not in the lake area."

Comment b) Page 2386, lines 15/16. "The thickness varies. . .." Not necessary to use the word "thick" in same sentence.

> **Response:** We agree. We have changed the text to read
>
> "The thickness of the glacier varies from 40-60 m near the lateral moraines to over 200 m in the center of the glacier."

c) Page 2387, line 8. As above the word "thick" in the same sentence is repetitive.

> **Response:** We agree. We have changed the text to read
>
> "The results of the GPR survey for the transect across the Imja-Lhotse Shar glacier show that the ice-bedrock interface is significantly below the lake bottom with an ice thickness over 200 m in the center of the glacier."

d) Reference 30, Hagen et al. correct spelling of Fürer-Haimendorf.

> **Response:** We agree. We have corrected the text.

e) Reference to Hammond. . . . . better to state that MA thesis is unpublished.

> **Response:** We agree. We have corrected the text.

Comment f) I have learned from one or other of the authors (Byers or McKinney) that there is a proposal by one of the UN agencies (UNDP or UNEP) that the risk of a dangerous outburst could be reduced by artificial lowering of the level of Imja Lake by a few metres. They (my informants) believe this would be a waste of money and would achieve little. I would agree. But should this not be stated in the conclusion? By the same token, as a great deal of exaggeration about the imminence of a catastrophic outbreak has been extensively publicized, I would like to see this point discussed in the conclusion, at least briefly. However, I would defer to the authors on this point.

> **Response:** Yes, there is, indeed, a project (funded by the Global Environment Facility through the UNDP and implemented by the Government of Nepal) that is now designing and installing a lake lowering system for Imja Tsho. The intent of the project is to lower the lake level at least 3 m in the hopes of reducing risk downstream. Our work has shown that unless the lake is lowered at least 10 m (and we recommend 20 m), there will not be significant flood risk reduction in communities downstream of the lake. That work will be submitted for publication in other papers. However, that work is beyond the scope of this paper and without presenting adequate quantitative results to substantiate these claims it does not seem appropriate to raise them in the conclusions section.