RECENT EVOLUTION OF PROGLACIAL LAKES NEAR MOUNT ELBRUS

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Glacial lake outburst floods have been reported for a long time. The first record of a glacial lake outburst flood is dated to the late 16th century when a lake near the Gietro glacier in Switzerland burst and 140 people died [1]. On December, 13 1941, the moraine that dammed the glacial lake Palcacocha in Peru burst, triggering an outburst flood that destroyed the part of the city of Huaraz and killed 6,000 people [2]. In 2003 the threat of another outburst flood was widely covered in the mass media resulting in a loss of US$ 20 million due to markedly reduced tourist flow [3]. In 1985 the Dig Tsho Lake outburst in Nepal destroyed a hydroelectric power plant and forced the government to abandon its plans to construct a new more powerful plant resulting in an estimated loss of US$ 500 million [4]. The increasing speed of glacier melt that has been recently reported in most mountainous regions increases the number of hazardous marginal lakes [5]. Just few years may pass from the lake formation and its outburst so neither the government nor community can be prepared to cope with the disaster. That is why it is important to monitor glacial lakes from their formation to outburst.

The subject of our research was proglacial lakes located near Mt. Elbrus. Although those lakes are relatively small, they have burst on repeated occasions and destroyed infrastructure in the region [6]. The objective was to study how proglacial lakes have changed in recent years, evaluate the probability of and model potential lake outbursts, outline flood risk zones and develop an early warning system for subjacent areas.

The main target was a group of lakes located on the margin of the Bashkara Glacier (in the upper reaches of the Adylsu River, Fig.1). We have been monitoring these lakes since 1999 [7]. The monitoring program consisted of yearly bathymetric surveys and shoreline mapping (since 2001), photomapping (in 1999, 2005 and 2007), and water level measurements (during frost-free seasons since 1999). The shoreline contours were surveyed using the Theo 010 B theodolite and also the Garmin eTrex Summit when going round the lakes. The depths were measured from a 15-30 m diameter inflatable boat using the Garmin GPSmap 188 Sounder that combines a GPS receiver and a dual beam echo sounder capable of working at depth from 0.5 m to 100 m. The water levels were measured from temporary tide gauge stations. All measurements were taken in the Universal Transverse Mercator (UTM) coordinate system with the WFS84 ellipsoid. The charts and calculations of water volume and bottom deformations were prepared using the Surfer 8.0 and ArcView 3.2 software. To understand how the Lapa Lake area changed in 2006 and 2007, the EROS high resolution (2 m/pixel) space images were used alongside with conventional methods. The currents of the Bashkara Lakewere measured using the Aanderaa Doppler Current Profiler in summer of 2007. Since 2008, bathymetric surveys have been carried out using the Lowrance 525CF echo sounder that effectively measures water depth. The early warning system based on the ADU-02 automatic water level sensor was installed at the Bashkara Lake at the same time. The parameters of a possible glacier lake outburst flood in the Adylsu River Valley were estimated using the River2D [8] and FLO-2D [9, 10] hydrodynamic flow models. The following datasets were used for modeling: a digital elevation model (DEM) of the Adylsu River Valley based on a 1:25000scale map dated 1957 and updated in summer 2008 using the kinematic GPS survey results, ASTER (15 m/pixel) and EROS (2 m/pixel) space images of the study area, and the lake outburst hydrograph simulated by the experts of Sevkavgiprovodhoz JSC using Y. Vinogradov's model [11]. The other lakes were covered by reconnaissance, bathymetric, and topographic and geodetic surveys. To assess how the lakes have changed in recent decades, topographic maps and aerial and space images from different periods were used.

The reported changes in the area and volume of the Bashkara Lake are due to water level fluctuations and depended largely on when the bathymetric survey was carried out. The area of the lake varied from 60,000 to 70,000 m^2 and the volume changed from 750,000 to 800,000 m^3. The maximum depth of the lake is 34 m. The deepest section has an elongated shape and occurs close to the southwestern ice-covered shore (Fig.2), where the lake bottom has the steepest slopes. As opposed to the Bashkara Lake, the subjacent lakes have been growing rapidly in recent years. In 2001 the Lapa Lake had a length of 120 m, width of 90 m and depth of 8 m. By 2006 the lake area increased by three times and the volume increased by five times with the maximum depth reaching 14 m (Fig.2 and 3). The Mizinchik Lake which dimensions in 2001 were similar to those of the Lapa Lake was filled with fluvioglacial sediments and almost disappeared by 2005. For the same reason, in 2008 the water volume in the Lapa Lake decreased by 20% as compared to 2006 (Fig.3). As a result of the rapid growth of the Lapa Lake in recent four years, the width of glacier damming the Bashkara Lake has decreased from 500 m to 250 m. Seasonal fluctuations in water levels on the Bashkara Lake vary commonly from 1.5 m to 2 m. The lake has the highest water level in early summer. By the end of June it decreases slightly and remains quasi-stable for the remainder of summer. In late August and early September, the water level decreases rapidly, and from October to May it is minimal. In summer daily fluctuations in the water level average 7-8 cm reaching 20 cm as a result of heavy rainfall. Within the period covered in this report (from 1999 to 2008), the water level of the Bashkara Lake used to increase both in summer and fall. From 1999 to 2002, the water levels were similar; in summer of 2003 the water level increased by 0.4-0.5 m and in 2005 – by 1 m. In 2006 and 2007 the water level did not increase but in 2008 it was 2 meters above the reported maximum level having triggered the lake water to overflow the moraine dam into the glacier drainage system. In summer the range of daily water level fluctuations on the Lapa Lake averages 10-15 cm; the long-term water level range is quite narrow.

The resulting models show that if a flood or a mudslide occurs, the outburst flood wave will move along the Adylsu River Valley quite quickly. The peak flow will reach the river mouth (8 km away from the possible outburst location) in 30 minutes and the Dzhantugan mountaineers camp – in 15 minutes. The largest depths (up to 9 meters) will occur in narrow and steep sections of the valley, which are quite numerous in its middle portion. The speed of the flood wave or mudslide will be the highest in the same places reaching 10-12 m/sec and 12.8 m/sec correspondingly. Most off-channel portions of the valley bottom will be flooded to 0.5-1.5 m at an average flood wave/mudslide speed of 0.7-1.5 m/sec. In the valley narrow portions, the flow width will be 20-30 m. In wider portions the flow width may reach 100-150 m (Fig.4). The flow may destroy bridge footings and light wooden buildings. The inhabited buildings of the Dzhantugan mountaineers camp and Ochag Shelter are located outside the risk area but the campsite located on the opposite side of Dzhantugan may be partially destroyed by the mudslide.

To our knowledge, in 2005 the total area of proglacial lakes near Mt. Elbrus was about 500,000 m^2 increasing steadily during the last 50 years. The exceptions are the Syltrankel Lake and the Donguzounkel Lake whose water spread areas did not increase. The lakes in the upper reaches of the Malka River have changed the most. To our knowledge, their total area increased over 6 times from 1957 to 2005 and reached 250,000 m^2 (Fig.5). The rapid growth of those lakes was caused by melting glaciers of Birdzhalychiran and Chungurchatchiran and led to the outbursts of some of them. For example, a lake covering an area of about 80,000 m^2 outburst some year between 2001 and 2005 but no significant mudslide occurred due to the small volume of the lake. In 2006 we forecasted the outburst of the lake covering the area of approximately 90,000 m^2 and holding 550,000 m^3 of water. On August 11, the lake did outburst and 400,000 m^3 of water were released resulting in a mudslide that destroyed the infrastructure of the Dzhilysu Resort. At the place of the old lake there are now 4 small lakes having a total area of about 13,000 m^2.

The water exchange between the Bashkara Lake and the glacier appears to occur through slow water filtration. While measuring the currents in the Bashkara Lake in 2007, we did not find any significant outlets. Therefore, seasonal fluctuations in the lake level are a result of water exchange in the “glacier-lake” system: water accumulates in voids and cavities within the glacier during the ablation period and then drains into the lake, i.e. meteorological factors (temperature rise, snowmelt or ablation) have nothing to do with the water level fluctuations. An increase in the lake level during the period of record appears to be caused by changes in the glacier drainage system.

A rapid rise in the Lapa Lake water level in the early 21th century was a result of climatic anomalies that caused melting of the Bashkara glacier.

The River2D model is easier to use while the FLO-2D model allows for many local factors such as roads, buildings, etc. The flood flow models generated using both River and FLO-2D are very similar so we may hope that they are true. We suppose that proglacial lakes are more likely to become silted with fluvioglacial sediments or move away from the glacier and become quasi-stable than to outburst.

Today the most dangerous glacial lakes around Mt. Elbrus are the Bashkara lakes. The range of the seasonal water level fluctuations on the Bashkara Lake is 1.5-4 meters and depends largely on the water exchange between the glacier and the lake. The range of seasonal water level fluctuations on the Lapa Lake is much less and depends largely on glacier ablation, rainfall and air temperature. The Bashkara Lake bottom has been stable in recent years and the water volume depends on the lake level fluctuations. From 2001 to 2008 the area of the Lapa Lake increased 3 times and the volume increased four times due to the melting of both Bashkara glacier and thermokarst on dead ice. To warn people of the danger we installed warning signs and developed an early warning system for glacial lake outburst floods. Other proglacial lakes around Mt. Elbrus are unlikely to outburst; besides, they do not pose much danger to people and infrastructure. However, one should be kept in mind that proglacial lakes are very dynamic and must be constantly monitored.

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Captions:

Fig.1. Bashkara lakes in 2004: Lake Bashkara (a), Lake Lapa (the large one on the left) and Lake Mizinchik (the small one on the right) (b).

Fig.2. Bathymetric map of Lake Bashkara (a) and Lake Lapa (b) as at August 2005

Fig.3. Changes in the area and volume of Lake Lapa from 2001 to 2008

Fig.4. Possible damages in the Adylsu River Valley as a result of potential outburst of Bashkara lakes

Fig.5. Changes of proglacial lakes in the upper reaches of the Malka River from 1957 to 2005: 1 – lakes in 2005; 2 – lakes in 1957; 3 – glaciers in 2005; 4 – glaciers in 1957; 5 – rivers in 2005 (prepared using an aerial photo taken on 22 August 1957 and a Kodak DCS760C space image taken on 19 August 2005)