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THE OUTBURST OF BASHKARA GLACIER LAKE (CENTRAL CAUCASUS, RUSSIA) ON SEPTEMBER 1, 2017

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The outburst of Bashkara Lake on September 1, 2017 reflects the current stage of glacier downwasting when the stable regime of lakes, debris complexes and glaciers is disturbed. We have estimated the parameters of the lake outburst, as well as threshold and trigger conditions using ground-based and aerial observations, satellite imagery analysis, and instrumental data obtained from a drone, an echo-sounder, an automatic weather station, and a water level datalogger. An abnormal shower with 100 mm of precipitation happened during a night from August 31 to September 1 following the previous (August 30–31) 45 mm rainfall, has been recognized as the trigger of the lake outburst. The volume of the liquid phase of the debris flood was about 1.1 mln m^3, including water released during the lake outburst (0.8 mln m^3). In the valley of the Adylsu River, the volume of 0.35–0.50 mln m^3 of debris was entrained into the flow. Based on this research, we propose recommendations on measures how to prevent emergencies which could take place in the area.

Glacial lake outburst flood (GLOF), debris flood, Caucasus

INTRODUCTION

At the night of September 1, 2017, a disastrous debris flood struck the valleys of the Adylsu River and Baksan River in the Elbrus area (Kabardino-Balkaria Republic, Russia). Three persons died. More than 3.3 km of the federal highway A-158 "Prokhladny–Baksan–Elbrus" and about 500 m of the highway in the valley of the Adylsu River were either fully destroyed or significantly damaged. Nearly 7750 local residents and tourists turned out to be blocked in the Elbrus area without transportation ties with the other part of the country, with the tourists' evacuation and delivery of essential goods exercised by way of a helicopter. Gas supply was suspended for six settlements – Terskol, Tegenekli, Elbrus, Neitrino, Baidayevka, and Verkhny Baksan. There was no electricity and no telephone connection (neither regular telephone nor mobile communication). Judging by preliminary official data published in Rossiyskaya Gazeta on September 8, the costs of the emergency works amounted to 160 million rubles, and the restoration of the infrastructure required for ensuring sustenance of the regions affected by the disaster was evaluated at 650 million rubles [*Myslivskaya, 2017*].

The flood was caused by the outburst of glacial Bashkara Lake (Fig. 1). The coordinates of the outburst place are 43°12′35″ N and 42°43′28″ E. In the late 1950s, the outbursts of Bashkara Lake resulted in destructive debris flows in the valley of the Adylsu River [*Kovalev, 1961; Seynova and Zolotarev, 2001*]. In those years, the body of the Bashkara Glacier was the lake's dam, and the outbursts moved along the subglacial channels. After formation of a subglacial (underground) drain channel with steady flow, the lake's outbursts stopped. The lake's regime was stable for about 40 years.

Variations in the masses of the glaciers of the Elbrus region, including the Bashkara Glacier, in the 1980–1990s brought about changes in the moraine landscapes and deformity of the existing and forma-

Fig. 1. Bashkara Lake and Lapa Lake in Central Caucasus after the outburst of September 1, 2017.

The quadrotor photo was provided by E.A. Savernyuk, 08.10.2017.

tion of new stadial moraines [*Dokukin and Savernyuk, 2012*]. In the 1990s, the overland flow from Bashkara Lake turned out to be blocked by a new lateral moraine up to 7–8 m tall, through which water began to flow down filtration channels [*Dokukin and Shagin, 2014*]. That in many ways determined the specifics of the lake's regime for the subsequent years. At the beginning of the 21st century, new lakes began to be formed at the place where the snout of the Bashkara Glacier was receding; they were named Lapa and Mizinchik [*Chernomorets et al., 2003*]. At that time, the volume and the area of Bashkara Lake depended on the water level fluctuations, but the growth of the lakes' volume downstream from the glacier with episodic rises in the level of Bashkara Lake indicated the increasing threat of the debris flow [*Chernomorets et al., 2007a*]. The increased probability of Lake Bashara's outburst was repeatedly written about, for example, in [*Zalikhanov et al., 2009; Petrakov et al., 2012*].

In 2008, overflow of water from the lake to the moraine dam into the grotto of the Bashkara Glacier was first recorded [*Kidyaeva et al., 2013*], with the probability of an outburst estimated to be high [*Petrakov, 2008*]. No outburst occurred, and a pavement was formed at the place of the overflow, which prevented further erosion of the river channel. The Chief Emergency Department of the Kabardino-Balkaria Republic carried out certain preventive actions, aimed at informing the population and at monitoring the lake's condition. In particular, at the place of the overflow of Bashkara Lake, a cut-through 1.8 m deep was made in 2009, resulting in reduction of the maximum volume of the lake by approximately 100 000 m^3. Based on the calculated hydrograph obtained by the specialists of "Sevkavgiprovodhoz" [*Gnezdilov et al., 2007*], the probable outburst flood from Bashkara Lake was simulated [*Petrakov et al., 2012*].

In the period of 2009–2014, the level of Bashkara Lake was not high, and there was no overflow of water over the moraine dam, but in 2015–2017, the water level rose high in the lake, the overflow was recorded every year, and its duration extended from one week in 2015 to two months in 2017. The field observations and the aerial survey revealed water filtration through the moraine dam. Thus, after a relatively stable period of 2009–2014, the probability of the lake's outburst rose again.

The goal of this work was to analyze the causes of the outburst of Bashkara Lake and to make preliminary estimation of the volume of the outburst flood.

MONITORING OF BASHKARA LAKES BEFORE THE OUTBURST

The methods of monitoring the group of Bashkara lakes have been described in detail in [*Petrakov et al., 2012*]. The bottom of Bashkara Lake, dammed up by the flank moraine and the glacier, was stable, which allowed, as a result of bathymetric survey (2001, 2002, 2003, 2004, 2005, 2008, 2009, 2012), evaluation of the relations between the water volume in the lake and the water level of the lake. The bathymetric curves were used to estimate the volume of water in the lake before the outburst.

Since 2013, to monitor the water levels of Bashkara Lake, scientists have used Keller DCX data loggers (Switzerland), measuring water levels by the piezometric method. One of the loggers was placed underwater and logged the total atmospheric pressure and the pressure of the water column above the logger in time, while the second logger was placed on the shore and measured the atmospheric pressure for making an adjustment by its value when calculating the water level, as well as the air temperature. The data reading was conducted simultaneously at the end of the season. As a result of the data loggers' operation, detailed behaviors of the water levels and the water and air temperatures were recorded for the flood-hazardous period, with the data saving rate in the device memory being once an hour. These water level data recorded with the Keller DCX data loggers are in good agreement with the foot-gauge measurements and the results of the preceding measurements conducted with the ADU water level gauge.

Thus, with the same level of detail, the behavior of the water levels and of the water and air temperatures was determined for the flood-hazardous periods of 2013–2017. The error rate in measuring the water level with the data logger was 1–3 centimeters.

The meteorological data for the period preceding the lake's outburst were obtained using the Davis Vantage Pro 2 automatic meteorological station. The station was placed on a subhorizontal site at the altitude of 2650 m and at the distance of 500 m from Bashkara Lake, on the stationary Dzhankuat Glacier gauge station. The temperature gauge was at the height of 1.8 m above the glacier surface. The temperature measurement error was 0.5 °C, and that of precipitation was 0.5 mm. All the measurements were conducted once every 15 minutes.

STUDYING THE CONDITION OF THE LAKES AND OF THE COURSE OF THE OUTBURST FLOOD

To evaluate the situation before the outburst, materials of the traverse studies conducted by M.D. Dokukin and R.K. Kalov in June and by V.V. Krylenko and A.A. Aleynikov in the second half of August 2017 were used. Aerial survey and current monitoring were carried out onboard a helicopter of the Kabardino-Balkaria Department of the Russian Ministry of Emergencies, with M.D. Dokukin, R.K. Kalov, M.Y. Bekkiev and M.M. Khadzhiev participating (September 1 and 10, 2017). On September 1–8, A.M. Smirnov, V.M. Kidyaeva, I.V. Krylenko carried out the land studies of the depressions of Bashkara Lake and of Lapa Lake, which included tracing the lake contours, recording the shore line before and after the event and recording the runoff processes in the catchment of Bashkara Lake, and repeated photos of the locality from fixed points. That allowed the scientists to detect changes on the slopes and in the river channel and to compare the situation after the outburst with that of the previous years. In addition, this team of researchers obtained information about the discharge of water due to the GLOF and the amount of the debris carried from the gauges established in selected conditionally stable characteristic points of the river channel. The maximum levels of the flow and the value of the fall in the water level of Bashkara Lake were evaluated by the high-water benchmarks with Bushnell laser rangefinder. The width and the depth of the gully were measured, and the areas of the cross sections of the flow were determined. M.D. Dokukin and R.K. Kalov evaluated the flood parameters in the downstream part of the flow in the Adylsu Valley and the effect of the shore-protecting structures on September 15. Aerial survey of the lakes and of the glacier-adjacent area was conducted from the Phantom 4 drone, and the bathymetric survey of Bashkara Lake and of Lapa Lake, the tracing of the external contours of the lakes and the examination of the area along the flood course were conducted by S.S. Chernomorets, E.A. Savernyuk, M.D. Dokukin, A.V. Khatkutov on October 7–9, 2017.

In addition, to analyze changes in the region of the outburst flood, satellite and space station images were used: from the Kanopus B1 satellite – on 22.08.2017, 19.09.2017; from the Sentinel 2A satellite – on 26.08.2017, 28.08.2017, 02.09.2017, 05.09.2017, 10.09.2017, 07.10.2017; and the images taken by S.N. Ryazansky onboard the international space station on 03.09.2017.

DISCUSSION OF THE CAUSES OF THE LAKE'S OUTBURST

A high level of water at the end of the summer. The mean long-term water level mark in the summer period was about 2588 m. As a rule, peak values of the water level were recorded in the first half of the summer [*Kidyaeva et al., 2013*], whereas by the end of August, the water level decreased, according to the readings of the water level gauge and to comparison of the data of the aerial survey and of the field observations (Fig. 2). In total, before the outburst, the water level in the lake had high marks not typical of the end of summer (about 2591 m); during 2.5 months, the water surface flow over the moraine dam was observed; however, the water level in the lake, until the middle of the day of August 31, did not exceed the values observed on the preceding days. Water overflow, which confirmed the level gauge readings, was recorded during the traverse measuring of June 29, July 28 and August 18.

Heavy and long-term precipitation. In the first half of the day of August 31, 45 mm of liquid precipitation fell within 15 hours (from 23:00 of August 30 to 14:00 of August 31). That caused a 33-cm rise on the water level of the lake, and termination of precipitation in the second half of the day caused stabilization and even certain decrease of the water level in the lake. On August 31 at 20.00, anomalously intense rain, extremely rare in this region, started, according to the observation data from the Dzhankuat Glacier gauge station. In total, within 5 hours (from 20:00 August 31 to 01:00 September 1), the liquid precipitation according to the precipitation gauge was about 98 mm, with three local peaks with the precipitation intensity of about 40 mm/h observed at 20:45, 22:00 and 24:00.

The anomalous shower resulted in the slope debris flows into the valleys of the Dzhankuat and Shkhelda Rivers, detected by comparing the Sentinel 2A satellite images of August 26 and September 2 and recorded by the aerial survey of September 1. In the colluvial-proluvial deposits of a slope, a gully about 800 m long and 20–40 m wide was formed. The area of the deposits of the slope debris flooding the pocket of the right flank moraine of the Shkhelda Glacier amounted to more than 32 thousand m^2. The debris flood deposits up to 100 m wide were recorded in the areas close to the glacier.

Fast rise of the water level before the outburst. As the subsequent reading of data from the logger showed, already in the first hour of the anomalous shower (from 20 to 21 o'clock) the level mark in the lake grew by 12 cm, with the rise continuing in the

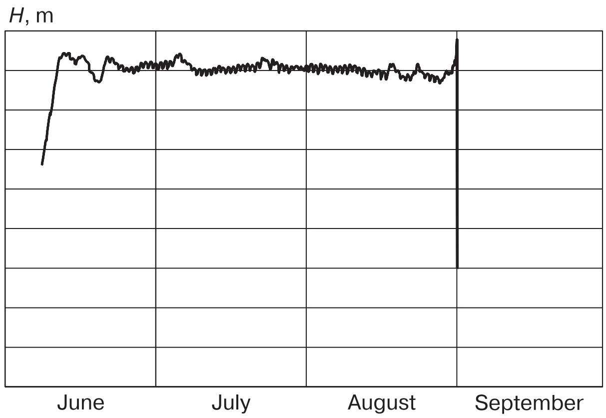


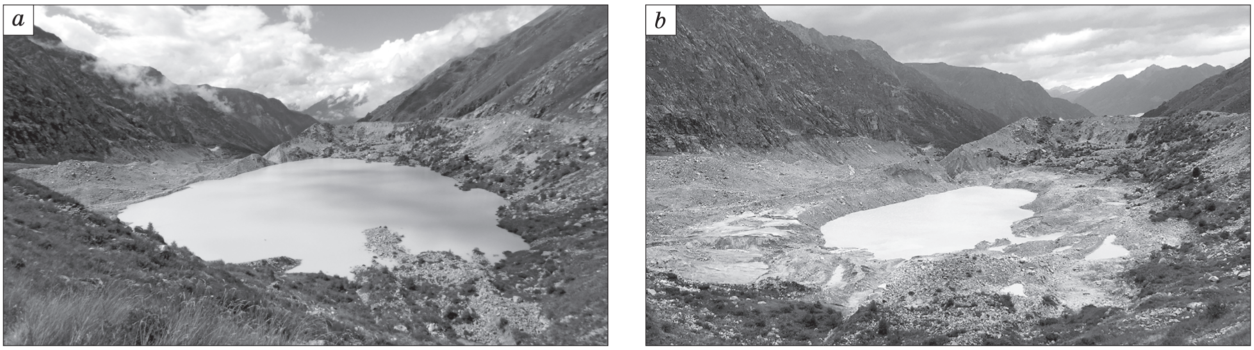
Fig. 2. Variations in the water level in in Bashkara Lake in the summer of 2017.

The horizontal lines are drawn every 1 m. After the outburst of 01.09.2017. The water level dropped by 16.5 m, but the level gauge recorded data only until it reached the surface.

lake until the outburst. In the lake, the water level was 55 cm higher on September 1, compared to August 31 at 20:00, and was 578 cm above the level gauge. In the period of direct observations, such fast growth of the water level had not been observed. By the following observation benchmark at 3 o'clock in the morning, the gauge level was already above the water level, i.e. at least 6-m discharge of water had already taken place (Fig. 2).

Evaluation of the volume of the debris flood. As a result of the outburst, the moraine dam was washed out, and by the morning of September 1, the water level had dropped by 16.5 m compared to the time before the outburst (Fig. 3), and the volume of water in the lake decreased by 3/4 (from 1 million m^3 to 200 thousand m^3). A catastrophic flood streamed down the Bashkara Glacier and further along the Adylsu Valley, in some areas turning into a debris flow. The roughly estimated inflow of water in the period of the anomalous shower (the lake's catchment basin is about 3.8 km^2, the total precipitation is 100 mm, and the runoff coefficient is 0.6) could reach 200 thousand m^3. At least the volume of 50 thousand m^3 of water was drawn into the flood during the outflow of water from Lapa Lake located near the lower end of the Bashkara Glacier (the mirror area of which before the flood was about 60 thousand m^2) as a result of the catastrophic flood. This is indicated by the reduction in the water level of Lapa Lake by approximately 80–100 cm below the long-term water level observed before the outburst flood. In the valley of the Adylsu River, the additional volume of water involved into the outburst flood consisted of the river channel supply and of the lateral inflows. In the period of the rainfall flood, before the outburst flood, the hydromorphological characteristics of the Adylsu River channel were taken in the first approximation to be the following: the mean width was 8–10 m, the mean depth, 1 m, and the mean velocity, 2 m/s. Considering the flow velocity in the river and the advancement velocity of the frontal wave of the outburst flood, the volume of not less than 50 thousand m^3 was involved into the outburst flood due to the river channel water supply. Considering the short-term passage of the outburst flood, the authors supposed that the contribution of the lateral inflows was compensated by the losses of the flow due to spreading-out in the flood plain and run-ups. In the preliminary estimate, the volume of the water component of the debris flood amounted to about 1.1 mln m^3.

The volume of the debris component was evaluated on the basis of the profiles made during the ob-



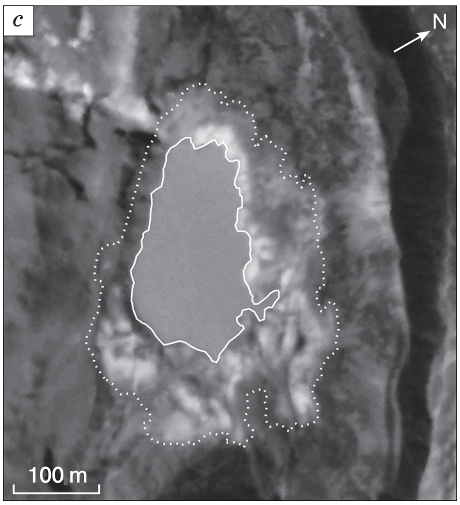


Fig. 3. Bashkara Lake before and after the outburst.

a – the photo was provided by V.V. Krylenko, 19.08.2017; *b* – the photo was provided by A.M. Smirnov, 01.09.2017; *c* – the space image Kanopus V1, 17.09.2017 (the solid contour – the shoreline on 17.09.2017, the dashed line – on 22.08.2017).

servation, analysis of photographs taken onboard the helicopter during the flyover immediately after the outburst and of space photographs taken onboard the international space station. The indicated lithodynamic zones are shown in Fig. 4.

According to the preliminary estimates, the volume of the debris involved into the outburst flood was 350–500 thousand m^3. The major mass of the debris was delivered into the flow due to lateral erosion in section 11 downstream from the bridge across the Adylsu River (200–300 thousand m^3, Fig. 4, *j*) and in section 9 downstream from the Dzhantugan sports base (100–150 thousand m^3, Fig. 4, *g*, *i*). Rather short sections of involvement of the solid material with prevalent bottom erosion section 1 (a cut, 20 thousand m^3, Fig. 4, *b*, *c*), section 4 (the frontal terrace of the moraine downstream from Lapa Lake, 20 thousand m^3, Fig. 4, *d*) and section 6 (the canyon covered by moraines of the Little Ice Age, 20 thousand m^3, Fig. 4, *e*) are located in the upstream part of the valley. The erosion sections are followed by the sections of debris accumulation or its transport and subsequent accumulation (Fig. 4, *f*, *h*, *k*, *l*).

EVALUATION OF THE VELOCITY AND OF THE RATE OF DISCHARGE OF THE OUTBURST FLOOD

According to the witnesses' evidence, the frontal wave of the flood reached the Shkhelda Gorge (6.4 km downstream from the source in Bashkara Lake) at about 01:20 a.m. and the settlement of Elbrus (10 km downstream from the source), no later than at 01:30 a.m. by 02:30 a.m. on September 2017, the discharge of water in the Adylsu River significantly decreased, as the loud sounds of crashing stopped). According to those figures, the advancement velocity of the frontal wave was 5–6 m/s.

The flood reached the Baksan River and passed several dozens of kilometers along it, causing destruction of roads, bridges, aqueducts, the gas pipeline and the electric power lines at certain places. Due to the passage of the outburst flood and due to the accompanying Baksan River channel deformities in the town of Tyrnyauz 40 km downstream from the lake, the crest of the debris flow dam on August 14–15, 2017 from the Gerkhozhan River was washed out by 2.0–2.2 m, and the level of the temporary dam pool, which existed from mid-August 2017, significantly decreased.

Judging by the traces left on the Bashara Glacier and in the upper part of the Adylsu Valley, the maximum outburst rate of water discharge could have amounted to about 500 m^3/s, while the rates of water discharge in the sections of local transformation into the debris flow 1.5–4.0 km downstream from the lake could have been even greater. For example, in the area of the bridge across the Adylsu River, the traces of the flood passage were recorded at the height of 7–8 m above the river channel. Considering the size of the bridge and the flow velocity of about 5 m/s, the rate of water discharge could have reached 800 m^3/s. Downstream in the Adylsu Valley, the maximum rate of water discharge gradually decreased, and near the exit to the Baksan Valley, it was approximately 200–250 m^3/s.

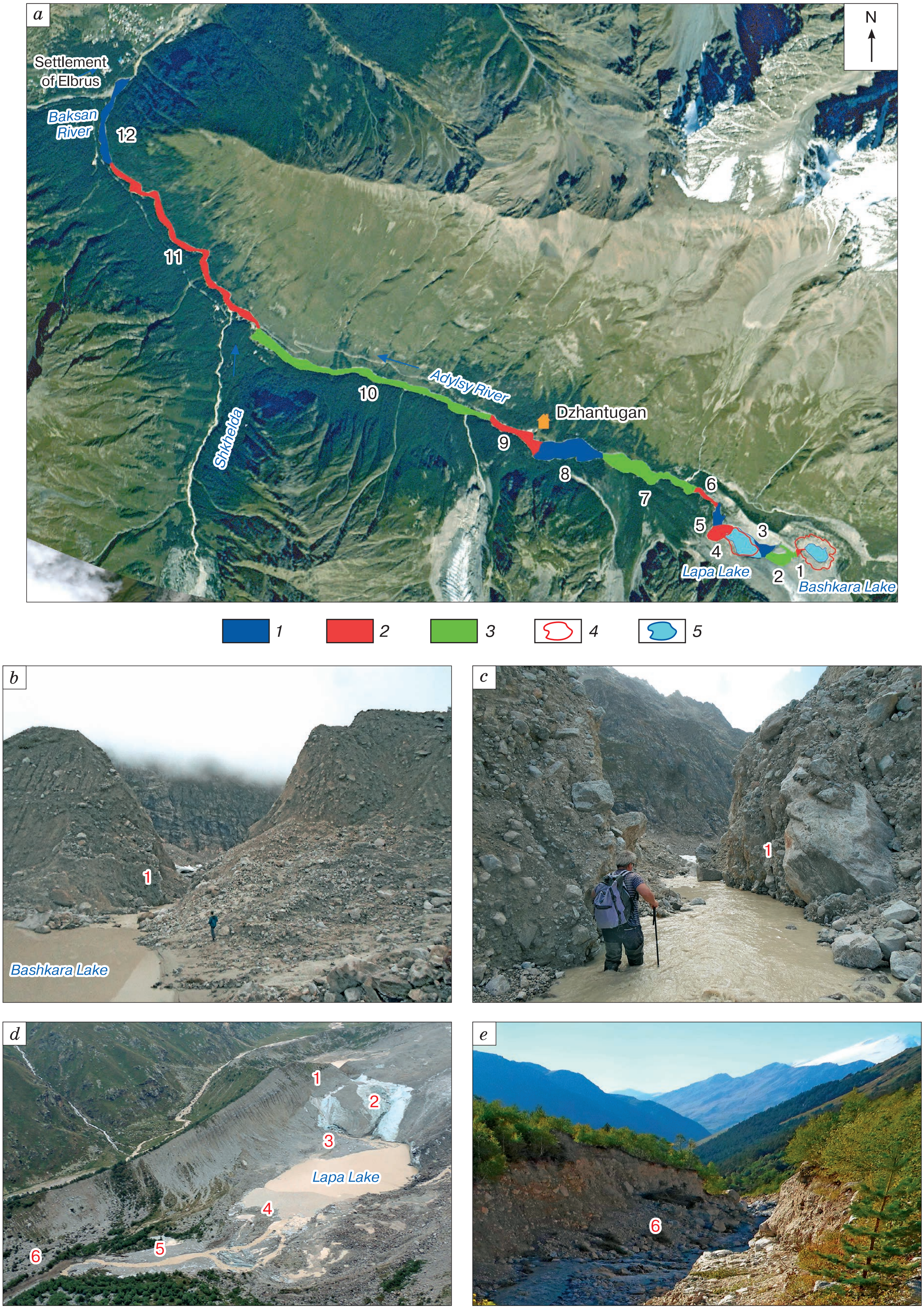
Continuing reduction of the Bashara Glacier. The surface of the Bashara Glacier, which propped up the dam in 2008, significantly decreased (Fig. 5). Retreat of the right branch of the glacier adjacent to Bashkara Lake on the front from 2009 to 2017 was 30–35 m, and that of the main flow of Bashkara Glacier adjacent to Lapa Lake from 2007 to 2017 was 100–105 m.

Decrease of the surface of Bashkara Glacier contributed to stability of the moraine dam. Whereas in 2008 it was backed by the glacier, this support has recently disappeared.

The probable mechanism of the outburst. Due to the inflow of a large volume of water as a result of anomalous precipitation, the flood with increased discharge of water moved across the moraine dam. The following factors contributed to that: 1) temporary rise of the water level in the lake by 55 cm due to cover of the surface runoff zone by the landslide masses coming from the moraine crest and its fast washout (the discharge of water could increase to several dozens of cubic meters per second – water was discharged in the area wider than before); 2) increase of the erosive ability of the flow as a result of its saturation with loose landslide masses having a large amount of fine soil.

Amid the abrupt rise of the water discharge over the ridge to 6–10 m^3/s, seepage through the moraine dam significantly increased. The increase of the hydrodynamic water head, together with reduced stability of the dam due to its inundation, could have caused violation of the dam pool's integrity, its shift and nearly instant crushing. Destruction of the moraine dam, which kept the lake, presumably occurred in two stages. At the first, very short-term, stage, the dam moved (crushed). At the second, longer-term, stage, after reduction of the water level in the lake by 8–10 m, a new narrow cut was formed due to bottom and lateral erosion. At this stage, the lake level dropped by 6–7 more meters.

Traces of an instant splash of water onto the glacier below (Fig. 1, 4, *d*) and the absence of any traces of terraces or of the stay of the interim water levels in the lake, which is observed in erosional destruction of the moraine dam (for example, [*Chernomorets et al., 2007b*]) suggest the high degree of probability of such a scenario. The trapeziform configuration of the upper part of the cut, where the main volume of the lake water was discharged, also supports this hypothesis. As a result, after fast filling of the funnel near the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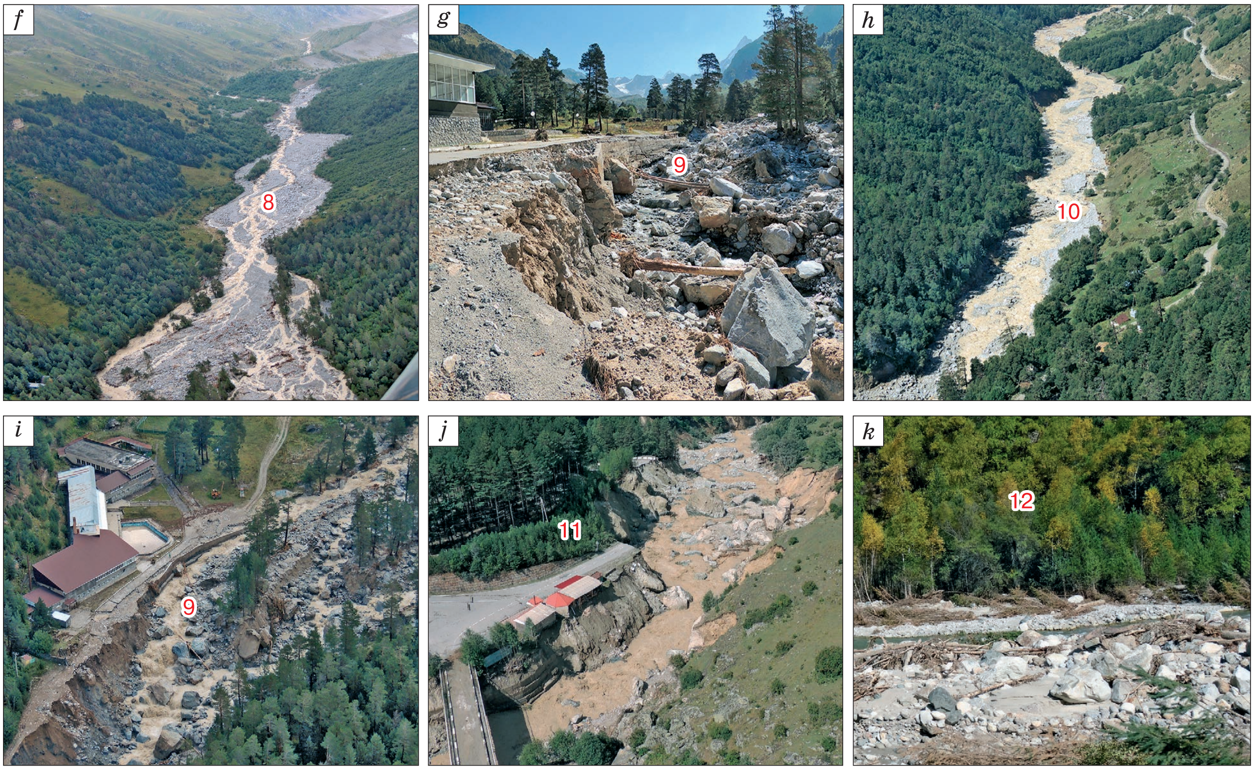

Fig. 4. The disaster zone in the valley of the Adylsu River before the influx into the Baksan River.

a – the prevailing types of the river channel processes in the valley of the Adylsu River at passage of the debris flood on 01.09.2017; *1* – accumulation of sediments; *2* – benthic and lateral erosion; *3* – sediment transport; *4* – the lake contour before the outburst on 22.08.2017; *5* – the lake contour after the outburst as on 03.09.2017. Lithodynamic zones: 1 – cut; 2 – Bashkara Glacier; 3 – the debris flow fan; 4 – the massif of terminal moraines with buried ice and of dead ice; 5 – sandur; 6 – a gully cut into moraines of the Little Ice Age; 7, 8 – the gorge of the Adylsu River above the Dzhantugan training base; 9 – the territory of the Dzhantugan mountaineering camp and the cut slope; 10 – the river channel downstream of the Dzhantugan training base; 11 – a bridge across the Adylsu River and the river channel downstream; 12 – the valley of the Adylsu River before its outcoming into the gorge of the Baksan River and the mouth of the Adylsu River. The diagram was made by V.M. Kidyaeva. The base: a photo from the International Space Station (the photo was provided by S.N. Ryazansky, 03.09.2017). *b*–*l* – photo illustrations for the diagram (the numbers of the lithodynamic zones are provided in red in the photos). The photos were provided by: *b* – I.V. Krylenko, 03.09.2017; *c* – V.M. Kidyaeva, 03.09.2017; *d* –*j*, *l* – M.D. Dokukin, 01.09.2017; *k* – S.S. Chernomorets, 07.10.2017.

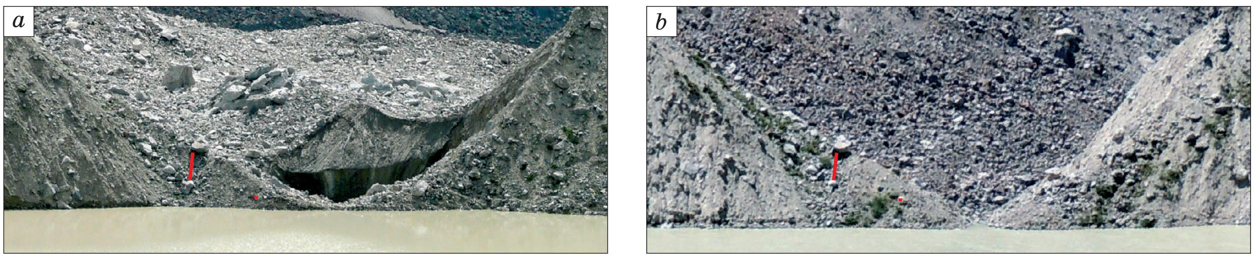

Fig. 5. Part of a morainic dam, Bashkara Lake, in 2008 and in 2017.

a – 16.07.2008; *b* – 28.07.2017. Lowering of the surface of Bashkara Glacier by more than 10 m. The red arrow illustrates the change in the position of rocks in relation to the maximum water level (*b*) compared to the level of 2008 (*a*). The photo was provided by M.D. Dokukin.

Table 1. **Parameters of Bashkara Lake and Lapa Lake after the outburst of September 1, 2017 (as of October 8, 2017)**

Lake	Area, thousand km^2	Volume, thousand km^3	Max depth, m	Average depth, m
Bashkara	26	216	18	8
Lapa	43	218	12	5

grotto (about 17–20 m deep in relation to the glacier margin), the water masses splashed onto the surface of the Bashkara Glacier. A large water wave passed, probably fast, on its surface.

The condition of the Bashkara lake and the glacier system after the outburst. The results of the bathimetric survey of Bashkara Lake and of Lapa Lake are shown in Table 1.

Bashkara Lake. Water flows from the lake across the crest of the dam (the crest mark is about 2574 m), the length of the dam is about 70 m, below the slope essentially increases, and the flow plunges into the subglacial grotto, with the area of the entrance cross section being 10–15 m^2. Within the dam water flows along a gully with the bottom 3–5 m wide and subvertical walls 15–20 m tall formed by the moraine (Fig. 4, *b*, *c*). Falling off of large lumps of ground from the walls of the cut (new material up to 30 m^3 was found) is hazardous, as it may cause rise of backwater in the lake, followed by washout of the dam pool. The possible rise of the water level may be decimeters–the first meters, the outburst flood during the washout would be insignificant and is likely to fully pass through the subglacial/intraglacial flow channel, performing the role of a regulator.

The area between the lakes. The width of the splash-in was about 50 m at the exist to the glacier below the grotto; then the flow widened to more than 100 m and divided into two branches (Fig. 4, *d*, zone 6). The main left flow streamed to the depression in the central part of the glacier, while the right flow passed as a relatively narrow stream 30–40 m wide closer to the right flank moraine and fell from a steep (approximately 30 m) cliff over the grotto, into which water flew from Bashkara Lake before the outburst. Due to a very high speed, the left flow "skipped" the part of the glacier with opposite elevation, rising to the height of more than 5–7 m, and reached the depression in the intensely fractured central part of the glacier, where it made a deep (up to 15 m) and wide hole, in which (perhaps, already at the end of

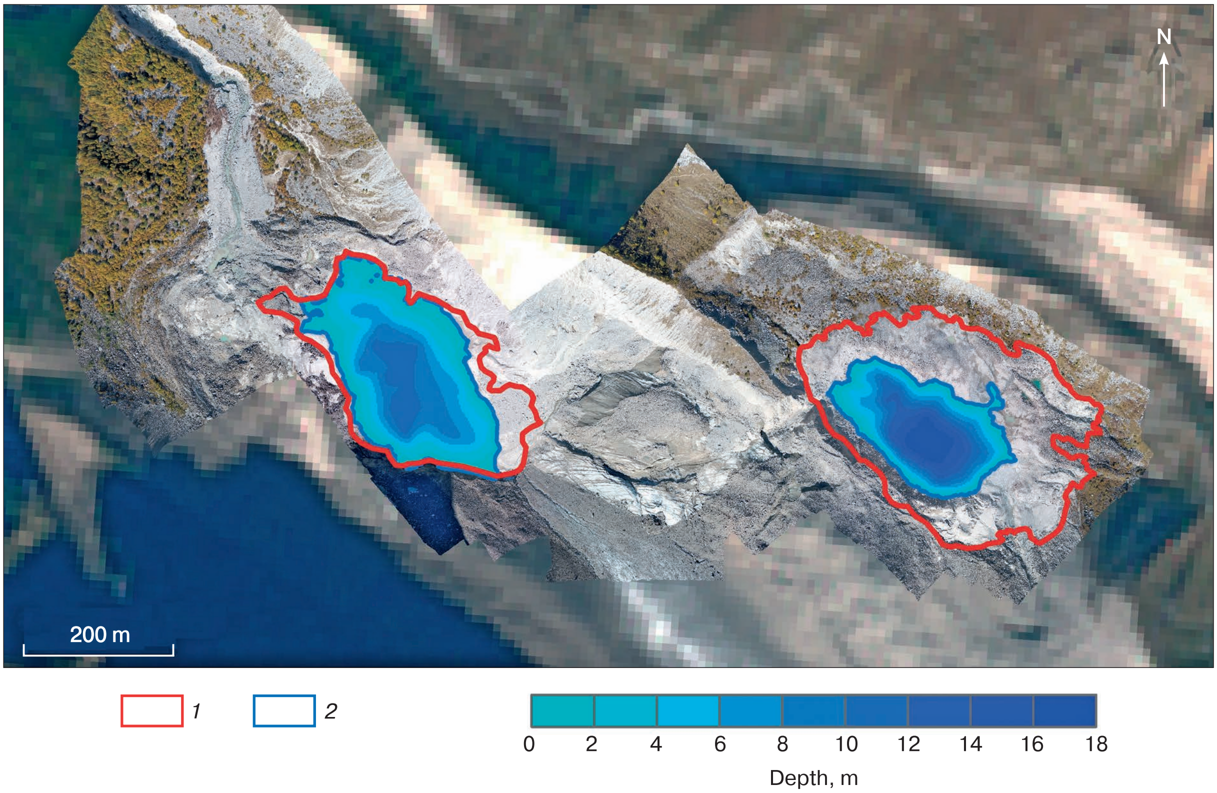

Fig. 6. Bathymetric maps of Bashkara Lake (*right*) and Lapa Lake (*left*) after the outburst.

The lake's contour: *1* – according to the space image Kanopus V1 as of 22.08.2017; *2* – according to the quadrotor survey of 08.10.2017. The base – a space image from Sentinel-2 as of 07.10.2017, the orthophoto is made of quadrotor images of 08.10.2017. The quadrotor survey and the bathymetric maps – E.A. Savernyuk, the orthophoto – A.I. Yarkova, E.A. Baldina.

the flood) large blocks of ice crashed down. On the steep edge scarp, the left flow gushed into Lapa Lake widely. It is likely that at the end of the flood the flow of water made a kind of a "funnel" several dozens of meters long and more than 20 m wide at the output in the lower part of the scarp.

Lapa Lake. The dam pond of Lapa Lake was formed by several terminal moraines containing buried ice. After the outburst, the lake water level remained to be approximately 1 m lower than the level in the pre-flood period, was well recorded by abrasion scarps on sandy beaches and by the thermal abrasion niche in the vertical cliffs of the ice banks. The overflow started as a wide flat flow of water, 60 m below there are steep spillways 3–4 m high. Below the spillways, the branches cut into a mass of dead ice 60 × 100 m in size, denudated by the outburst flood, to the depth of 3–5 m (Fig. 4).

As at October 8, 2017, the level of Lapa Lake decreased compared to the marks before the outburst by approximately 1.8 m. It is possible to forecast its reduction due to regressive erosion of the channel in the ice, along which the water spills.

In any case, erosion of the dam will take place in the shallow part of the lake (Fig. 6), and the possible discharge of water from the lake, without taking the incoming water into account, will not exceed 200 thousand m^3.

THE DEBRIS FLOOD ON SEPTEMBER 7 IN THE ADYLSU VALLEY

Comparison of the aerial survey materials as of September 1–10, 2017 revealed the fact of a debris flood that occurred on September 7. There were reports of the local residents of the partial erosion of the restored road near the settlement of Neitrino on September 7. Fig. 7 demonstrates a part of the Adylsu Valley in the area of the Elbrus training center after the outburst of Bashkara Lake on September 1 and on September 10, after the debris flow. The debris 1.5–2.0 m thick got deposited, and the flow went above the protection wall onto the territory of the Elbrus mountaineering camp. The presence of numerous erosions and deposits of loose material in the channel of the Adylsu River, which emerged after the outburst of Bashkara Lake on September 1, 2017, as well as intense liquid precipitation, a little over 70 mm during 15 hours, contributed to the debris flow.

CONCLUSIONS AND RECOMMENDATIONS

The outburst resulted in fivefold reduction of the volume of water in Bashkara Lake. Despite this, there exists the probability of a repeated outburst. The gully formed by the outburst is narrow and deep (Fig. 4, *b*, *c*). In the future, it is possible that the narrow cut in the moraine crest of Bashkara Lake may be overlapped as a result of a landslide to form a temporary dam up to 5 m high, resulting in the rise of the water level in the lake and in the further outburst of the formed dam.

In 2018, it is required that continuous control should be exercised over the condition of the dam between Lapa Lake and Bashkara Lake, and observation of their water level regimes should continue.

It is necessary to stop senseless and unprofessional attempts to reduce the water level in the lakes without examining all the related aspects. The global experience [*Liboutry et al., 1977*] indicates that such attempts may cause a disaster. A project of controlled discharge of water from the lakes is required. In particular, for Bashkara Lake, it is recommended to broaden the bottom of the evacuation channel to 10–15 m and to reduce the steepness of the adjacent slopes to 15–20°, to lay pipes, with subsequent reimbursement and making an emergency water discharge, as well as to use syphon pumping of the lake water annually in the period from the end of May to

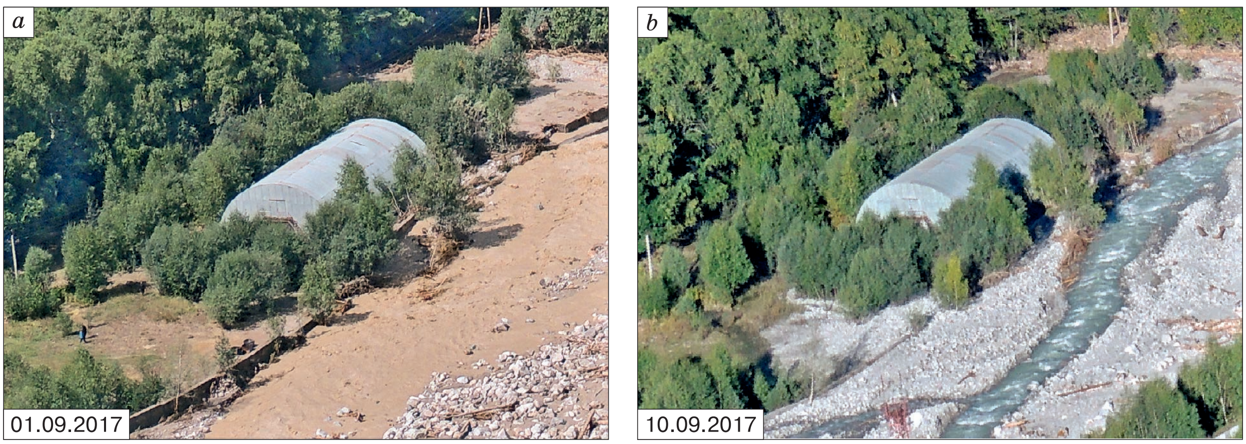

Fig. 7. The debris-flow-proof wall on the territory of the Elbrus training center before (*a*) and after (*b*) the debris flood of September 7 (the photo was provided by M.D. Dokukin).

September. The measures to be taken in relation to Lapa Lake require additional work (for example, it is possible to apply hydromonitors for washing out and broadening the ice dam).

The outburst of Bashkara Lake created new conditions for forming debris flows along the channel of the Adylsu River. There have appeared parts of unstable steep slopes composed of loose material. In the case of new flows flowing along the river channels or floods, mobilization of this material will be much easier than in the situation of September 1, 2017. Therefore, even if the water impulse is not so large, addition of solid material to the new flow may prove to be significant and result in new destructions. Events similar to the debris flood of September 7, 2017 will be repeated on a larger scale.

Parts of the lake shores protected by concrete walls withstood the destructive impact of the flood and of the debris flood (Fig. 7), implying the high effectiveness of these structures. In the future, reinforcement of the shores with concrete walls will contribute to minimization of damage due to possible recurrence of floods and debris flows. Destroyed and cut part of roads are located at the turns of the channel of the Adylsu River (Fig. 4, *j*), with the parts of the roads on which large rocks appeared due to the debris flood of September 1 appearing to be most problematic.

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