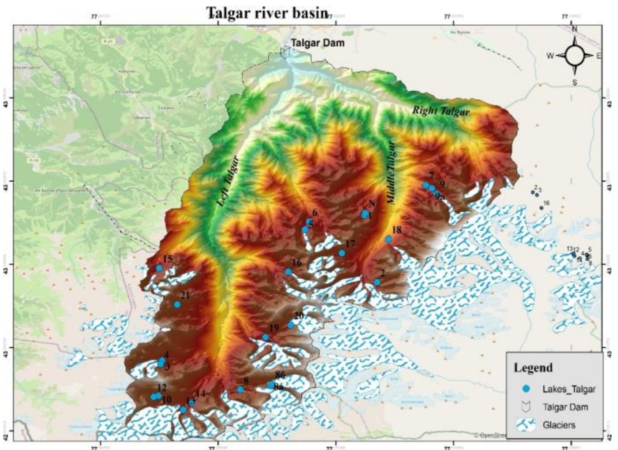
Report

of the4500512620 UNESCOAdaptation Fund project Reducing vulnerabilities of populations in the Central Asia region from glacier

lake outburst floods in a changing climate” (GLOFCA) in Kazakhstan.”

The Talgar River basin, situated in the Almaty region within the Ile Alatau Range, is notably susceptible to mudflows. This basin is formed by the confluence of the Left, Middle, and Right Talgar rivers, covering a total catchment area of 444.5 km². The Right Talgar River spans 15.4 km, the Middle Talgar River 18 km, and the Left Talgar River 31 km. The upper reaches of the basin are characterized by significant glaciation, comprising 129 glaciers and 24 moraine lakes, with seven being particularly prone to breakthroughs. To date, over 40 substantial glacial debris flows have been documented.



The Talgar River basin is classified under the highest category of mudflow hazard. This risk is predominantly associated with the Left and Middle Talgar Rivers, where debris flows, releases from moraine lakes, and potential mudflow massifs are observed annually. Notable mudflows originate from glaciers such as №105 'Komsomol', №109 'Ordzhonikidze', and the Middle and left Talgar mudflow gullys. Significant deposits of mudflow materials are present in the tributary beds, ravines, and scree slopes of the Talgar River. These deposits contribute to the overall flow during mudflow events. For instance, the mudflow originating from the incision under the Komsomol glacier extends approximately 2000 meters with an average width of 200 meters.

In the Middle Talgarcatchment, Lake Bezymyannoe, known for its instability, has repeatedly breached and subsequently refilled, making it particularly prone to breakthroughs. The presence of a substantial mudflow trench, along with loose clastic and erosive material within the trench, frequent landslides, and landslips, contributes to the formation of significant mudflows and outbursts. These events vary in flow rates and volumes of mudflow sediment. Between 1993 and 2003, the lake emptied annually, each time resulting in the formation of mudflows. In the upper part of the basin, new lakes have appeared and emptied without generating large mudflows.

On glacier №168 «Ozerny», there are numerous small lakes that burst annually, usually with minimal discharge. However, when these lakes are completely filled and then emptied, they can form substantial mudflows. Most moraine lakes in the Talgar River basin are non-stationary, typically emptying only during the winter period, and their hollow can remain empty for several years. Lake №8, located beneath glacier №127 «Toguzak», is one such non-stationary lake. It features three grottoes situated in the northern part of its hollow. If the intra-moraine drainage channel becomes blocked by an ice 'plug', the lake fills up and, upon thawing, begins to empty gradually.

Lake №19, located under glacier №131 «Kalesnika» in the basin of the Left Talgar River, transitioned from a stationary to a non-stationary state in 2021. During winter, the lake completely empties. In recent years, the Kalesnika moraine and glacier have experienced active thermokarst and thermo-erosion processes, resulting in new thermokarst failures, cracks, sinkholes, and numerous intra-moraine runoff channels.

Currently, Lake №19 is actively expanding northeastward, with approximate dimensions of 70 by 140 meters. Thermokarst sinkholes, appearing as large cracks, have formed along the bay, with cracks reaching depths of up to 3 meters and widths of up to 4 meters at the top. Active dynamics of all thermokarst processes are evident. A survey conducted on July 10, 2024, observed significant sliding of the moraine cover into the lake basin on the exposed areas of buried ice. The maximum depth in the bay reached up to 10 meters, while the maximum depth of Lake №19 itself is 17.9 meters. The lake contains several grottoes located at various places and heights, with several positioned in the central part, where the deepest point is found. Water outflow occurs below the ancient moraine in its middle part, where the flow connects with the main riverbed, originating from glaciers №131 'Kalesnika' and №133 'Severtseva'.

In the upper part of the left bank's unnamed tributary of the river, where glacier №103 Bogdanovich is situated, lies the unsteady Lake №15. This lake fills during the winter and spring periods and empties with a small discharge during the spring and summer periods. This area is a popular tourist destination due to a beautiful large grotto and the well-known trail 'Big Almaty Roundabout' that runs along the mudflow-prone river.

In recent years, global climate change has led to increased liquid precipitation in the glacial zone. This phenomenon has caused the moraine lakes to fill and overflow, resulting in the formation of mixed mudflows.

Methodology for forecasting mudflows of glacial genesis.

High daily air temperatures during the summer result in significant glacier ablation, subsequently leading to the filling and overfilling of moraine lake hollows. In the Talgar River basin, mudflows occur annually, originating from glacial, storm-induced, and mixed processes.

Kazselezaschita uses the «Methodological Guidelines for Making Alternative Forecasts of Mudflows of Glacial Origin in the ZailiyskiyAlatau»,developed by Kirenskaya and Talanov in the late 1980s, as a foundational framework for the prevention and forecasting of mudflows. This document serves as the basis for assessing the mudflow hazard of glacial genesis [1].In recent years, amendments and additions have been made to this methodology, incorporating changes in weather conditions and analyses of recent mudflow events.

According to this methodology, the mudflow situation is assessed using hydrometeorological data from the high-mountain zone. An analysis is conducted to determine the possibility of mudflow formation when critical values for key parameters – such as air temperature, height of the zero isotherm, amount of precipitation, water discharge, and their quantitative and cumulative data over specific time intervals are reached. Notably, muddflows may not occur immediately after these critical conditions are exceeded; instead, they can be observed several days later, sometimes up to 8-10 days.

Table 1.Critical values of the sums of mean daily air temperatures ($T_i{}^0C$) for different dates of the mudflow hazardous period

Criteria	June		July			August		
	Date							
	20th	30th	10th	20th	30th	10th	20th	30th
T_i=108% $\sum T_n$	201	284	370	479	551	655	743	821

Note: n = 1, 2, 3, ... N is the number of days from May 1 to a certain date of the following months.

Table 2. The average height of the zero isotherm for ten days before the forecast date is not lower than 4.2 km, and for 30 days - 4 km

Criteria	Numberof 24 hours	
	for 10 days	for 30 days
$Z_i=\sum(Z_{t=0})_n/n$, meter	4200	4000

Table 3: Critical values of precipitation layer (P_i, mm) for different time intervals preceding debris flows

Criteria	Numberof 24 hours	
	for 10 days	for 30 days
$H_i=\sum H_n$, mm	30	95

Thus, the forecasts of mudflows in 2014, 2015, and 2023 were fully justified. Based on their experience in mudflow prevention, specialists from Kazselezaschita have also made additional contributions and updates to this methodology.

In Figure 1, the trends in mean monthly air temperatures for July over the period 1970-2021, the elevation of the zero-degree isotherm for the period 1994-2021, and the years of moraine lake outbursts with significant discharges are clearly illustrated. The maximum elevation of the zero-degree isotherm reached 5426 meters a.s.l. on July 14, 2015.

Based on the graph, specific years (1973, 1997, 2014, 2015, and 2023) can be identified where temperatures exceeded the norm by 1-3.5°C, coinciding with moraine lake outbursts. In other years, lake outbursts were associated with accumulated heat from previous years or other natural factors.

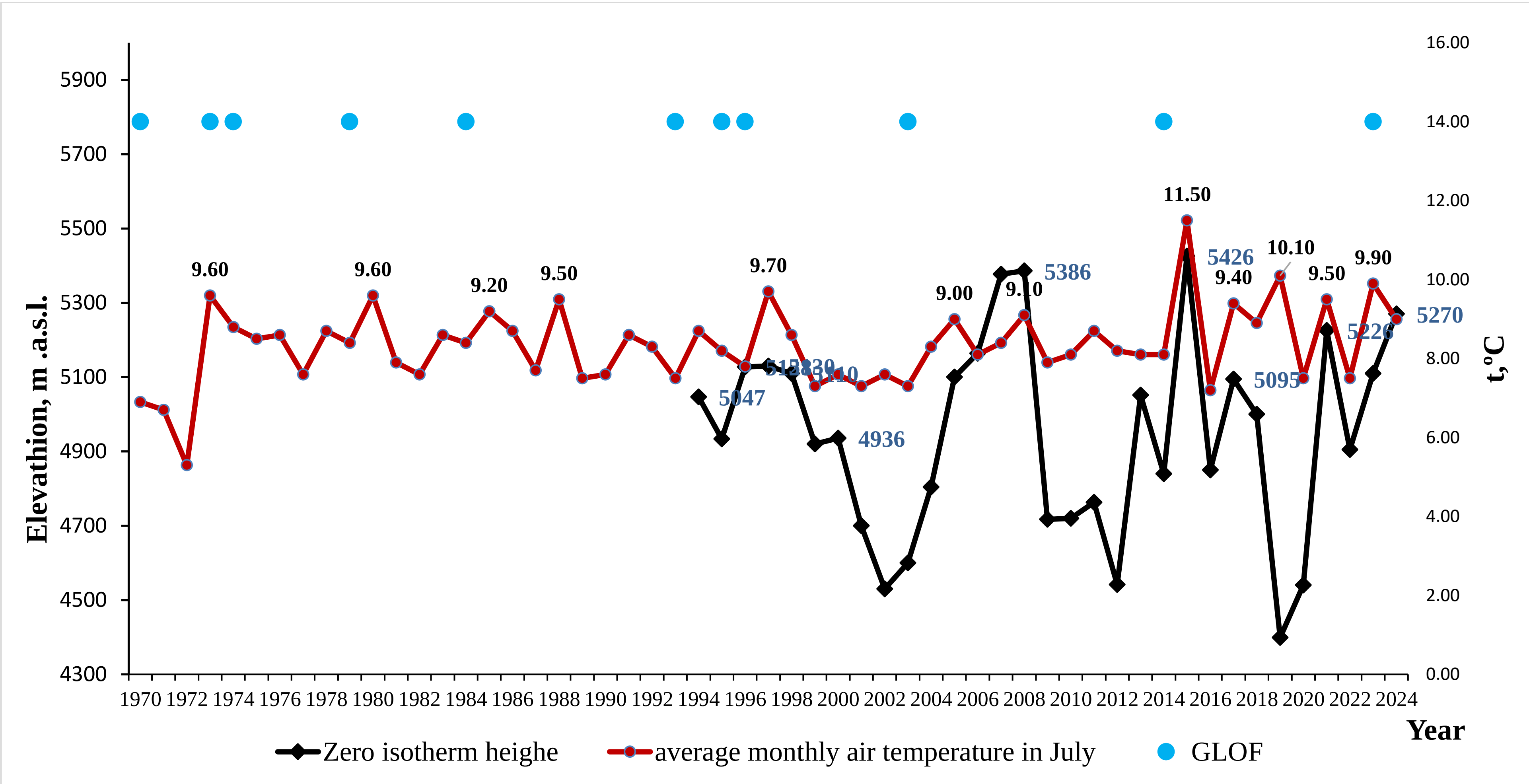


Figure 1. The combined graph of average monthly air temperatures in July, maximum height of the zero isotherm and GLOF

Recorded mudflows of glacial genesis

The mudflow situation in 2024 in the mountainous regions of the Ile Alatau range has been quite challenging, with glacial and rainfall-induced mudflow hazards persisting throughout the entire summer season.

In 2024, the elevation of the zero-degree isotherm in the Ile Alatau range exceeded 4000 meters a.s.l. for 68 days from June to August 25, which is 6 days longer compared to 2023. The average elevation of the zero-degree isotherm during the period from June 1 to August 25 was 4281 meters, while for the same period in 2023, the average height was 4258 meters above sea level. The maximum elevation of the zero-degree isotherm in 2023 was recorded on July 24 at 5110 meters, whereas in the current year it was observed on August 1, reaching 5270 meters.

On June 28, 2024, the zero-degree isotherm reached an elevation of 5033 meters, the highest June value recorded over the past 30 years.

Field and aerial surveys revealed active thermokarst and thermo-erosion processes on the modern moraine of the glacier and lake №19. Exposed buried ice was observed on the northeastern slope of the lake basin and along the flanks of the bay, with landslides of up to 1000 cubic meters occurring during warm hours of the day.

On July 28, 2024, around noon, a thermokarst sinkhole with a depth of approximately 10 meters and a diameter of about 20 meters formed north of the bay. Surveys of the modern moraine showed both longitudinal and transverse cracks in the form of sinkholes. Fresh cracks and sinkholes were observed along the bay, which are actively developing. The walls of the lake basin are unstable, and the water in the lake is turbid (dirty gray), indicating ongoing active thermokarst processes within the lake basin.

Figure 2. Lake №19 Talgar River basin (10.07.2024 taken by Saniya Beisenbayeva)

In recent years, the modern moraine of the Kalesnik Glacier has been characterized by active thermokarst processes, including the formation and disappearance of new lakes, the appearance of thermokarst sinkholes, subsidence, and craters. The lake continues to expand actively towards the northeastern part.

Furthermore, during ground and aerial surveys of lakes in the basins of the Uzynkargaly, Ulken Almaty, Talgar, and Turgen rivers, it was observed that cracks formed at the terminus of glacier tongues, resulting in collapses of several thousand cubic meters into the lake basins.

According to background assessments, the mudflow hazard of glacial and rainfall genesis in the mountainous regions of the Ile Alatau range remained extremely high in 2024 (all calculated parameters exceeded critical values). During aerial surveys of the mountainous terrain of the Ile Alatau range, small, non-stationary moraine lakes with limited volumes were identified, which drained without triggering mudflows.

When considering the most significant mudflows of glacial origin in recent years, the formation and passage of the debris flow on July 21, 2023, stands out as particularly noteworthy.

According to the data from RSE "Kazhydromet," the average annual air temperature across Kazakhstan in 2023 exceeded the climatic norm (1991-2020) by 1.73°C, making it the warmest year in the history of instrumental observations.

During the significant mudflow event on July 21, 2023, multiple mudflow basins across the Ile Alatau Range were simultaneously affected. These events involved various altitudinal zones ranging from glaciers (such as Ulken Almaty, Kishi Almaty, Talgar, and Yesik basins) to lowlands (specifically in the Uzyn-Kargaly river basin), albeit with variations from basin to basin. In some basins, processes affecting all altitudinal zones contributed to the initiation and transformation of mudflows (e.g., Talgar River basin), while in others, impacts were confined to highlands and midlands (e.g., Yesik River basin), and in some, only lowlands were affected.

Mudflows observed in the Talgar River basin occurred in mixed forms. In the Middle Talgar River basin, a water flow with an approximate rate of 4 m^3/s was released from beneath modern moraine, although it did not reach the seasonal gauging station 'Alplager' operated by Kazselezaschita.

On July 26, 2023, aerial surveys revealed significant traces of mudflow activity in the mudflow incisions under peaks such as Almaty (Komsomol) and Ordzhonikidze in the Left Talgar River basin. These traces included evidence of mudflows originating from the right side of the mudflow incision, likely triggered by precipitation on July 21, 2023. Within the incision, indicators suggested mudflow formations with peak flow rates reaching 40-50 m^3/s. Downstream, as the debris flow entered the MiddleTalgar River, the discharge was approximately 20 m^3/s, where the flow transitioned into a debris flood.

Throughout the Left Talgar River basin, traces of mudflows were observed in nearly all small tributaries, including dry ravines on the left side of the gorge, while minimal mudflows were noted on the right side.

During the aerial survey, water flow along the Talgar River was characterized as a sediment-laden flood. The turbidity of water in the Left and Middle Talgar Rivers within the high and mid-mountain zones was rated at 2-3 points.

Figure 3. Consequence of mudflow on 21 July 2023 at the dam of Talgar river (photo 22.07.2023 by ‘Kazselezaschita’).

Figure 4. Consequence of mudflow on 21 July 2023 at the dam of Talgar river
(photo 22.07.2023 by 'Kazselezaschita').

In July 2023, the height of the zero isotherm rose from 3110 to 5110 meters above sea level, reaching its peak on July 24, 2023. Throughout the month, the zero isotherm remained above 4200 meters for 16 days, a critical threshold indicating heightened mudflow risk. This elevation range encompasses the lower reaches of glaciers in the Talgar River basin, where maximum glacier ablation occurs, resulting in increased water discharge and elevated turbidity levels approaching those of debris flow floods.

Analysis of moraine-glacial lakes in the Ile Alatau Ridge revealed that on July 21, 2023, intense local rainstorms deposited over 70 mm of precipitation onto glaciers in the river basin. This sudden influx accelerated glacier ablation processes, significantly increasing water discharge within the river bed. In the high and mid-mountain zones of the ridge, both storm-induced and glacial mudflow events were observed, characterized by intense slope runoff, mudflow formations, the filling of lake basins, and the draining of moraine lakes. These events resulted in the deposition of mudflow sediments with substantial volume in the river bed.

The summer of 2015 was one of the hottest periods for the mountainous regions of the Ile Alatau range, with the elevation of the zero-degree isotherm in July ranging between 3455 and 5426 meters above sea level. According to background assessments, the mudflow hazard of glacial genesis during this time showed that most values exceeded critical thresholds.

Due to the prolonged high temperatures in the high-altitude zone, thermokarst processes within the modern moraine led to the drainage of Lake №1 in the Kargaly River basin through newly formed intra-moraine channels on July 23, 2015. As a result, at 2:20 AM on July 23, a mudflow event occurred in the Kargaly River with a maximum discharge of 25-30 cubic meters per second. The mudflow significantly altered the riverbed up to the Kargaly dam, deepening the channel and eroding the riverbanks. The mudflow gained mass through the erosion of the riverbanks. The solid material carried by the flow deposited approximately 150,000 cubic meters of debris in the sediment storage basin of the dam, with a significant portion of the deposits settling 500-1000 meters upstream of the Kargaly dam. The design capacity of the sediment storage basin is 1.2 million cubic meters. The water volume in the lake before the drainage was visually estimated at around 40,000 cubic meters, and the lake drained by about 80%.

Below the dam, the mudflow transformed into a debris-laden flood. Downstream, bridges were swept away, residential houses were flooded, and residents had to be evacuated.

In the mountainous regions of the Ile Alatau range, heavy rains fell in some areas during the day on July 24 and the night of July 25, 2015, with precipitation reaching up to 22 mm. The temperature remained high. On July 25, 2015, at 1:50 PM, a mudflow occurred in the Left Talgar River under Komsomol Peak, with waves discharging between 5 and 10 m^3/s. The mudflow was caused by intense glacier ablation and heavy rainfall.

In the Ulken Almaty River basin, on July 25 at 2:30 PM, a mudflow with a discharge of up to 300 liters per second originated under Sovetov Peak, merging into the Ulken Almaty River 100 meters upstream of the Kazhydrometgauging station, located above the Big Almaty Lake (BAL).

On July 17, 2014, at 12:05 PM, a mudflow formed on the left side of the gorge in the Middle Talgar River basin. The mudflow incision occurred 1.5 km downstream from the Kazselezashita's "Alplager" station. The mudflow resulted from the drainage of a lake under Glacier №150 through intra-moraine channels. The lake is situated on the modern moraine at an elevation of 3500-3600 meters above sea level. A similar event, with the drainage of this lake and the formation of a mudflow, occurred in 1993 (see Fig. 5).

Figure 5. Mudflow incision in the Middle Talgar River basin.

During the drainage process, the water level in the lake dropped approximately by 4 meters (see Fig. 6). The photograph shows the initial shoreline contours of the lake with traces of ice.

The discharge of the mudflow in the Middle Talgar River and after merging with the Right Talgar River was about 200 m^3/s. The mudflow traveled in a wave-like pattern, rolling boulders and stones. The turbidity of the flow was rated at 5 grades. As the flow approached the dam, large fractions of the mudflow mass were deposited. Approximately 300,000 m^3 of sediment accumulated in the sediment trap (see Fig. 6).

The mudflow inundated three houses of the forest ranger's station, destroyed a tractor road along the riverbed, damaged a section of the road leading to the Pioneer Camp "Sputnik," and destroyed the Kazhydrometgauging station. Within the city limits, the riverbanks were eroded.


Figure 7. Moraine Lake under Glacier №150.


Figure 6. Partially Filled Sediment Storage Basin Before the Talgar Dam.

Before the formation of the mudflow on July 17, 2014, a gradual decrease in the temperature background was observed. The zero-degree isotherm in July did not reach 5000 meters. From July 13 to 16, 2014, most values approached critical thresholds, with the exception of the total precipitation over the 10-day period.

The cause of the drainage of the moraine lake, as in 1993, was the opening of intra-moraine drainage channels from the lake due to rising air temperatures and significant precipitation.

Information on mudflows in the Talgar River basin

30.07.1940. Information on mudstone flow formed by collapse of moraine sediments in the upper reaches of the Left Talgar River (Bezymyanny brook) [3].

30.06.1960. as a result of a breakthrough through the intra-moraine channel in the basin of the Middle Talgar River, a flash flood occurred[4,5,6].

26.07.1961. In the basin of the Left Talgar River, as a result of the breakthrough of glacial lake №8, a sediment-laden flood was formed[5,6].

19.08.1961.A mudflow was recorded under conditions similar to those observed on 26.07.61.

25.07.1964. In the basin of the Left Talgar River, a mud(stone)flow was formed as a result of the breakthrough of a moraine lake and intramoraine reservoirs [3,6,7].

25.07.1965. As a result of the breakthrough of the moraine lake (through intramoraine runoff channels under the Kalesnika glacier (Left Talgar river basin), a mud(stone)debris flow was formed[7,8].

12.17.06.1966. In the basin of the Left Talgar River, mud(stone)debris flows were formed due to the collapse of moraines, intraglacial water outbursts, and of moraine lakes [5,6,9].

17.08.1968. As a result of intra-moraine water breakthrough and collapse of moraine sediments, a mud(stone)flow passed through the Left Talgar River [6].

20.06.1970. In the basin of the Left Talgar River, a mud(stone)flow was formed as a result of the breakthrough of Lake №5 under the Kalesnika Glacier through an ice tunnel[6, 8,10].

14.07.1970. The formation of the debris flow occurred as a resulted from the breakthrough of Lake №9 in the Left Talgar River basin, which occurred through intra-moraine runoff channels penetrating a 200-300 meter ice dam. The outflow volume from the lake was 47,000 m^3. The water outflow emerged 0.5 km below the lake, creating an erosion incision that facilitated mudflow formation. The maximum flow rate of the mudflow reached 100-150 m^3/s. Solid materials from the mudflow were deposited on the upslope sections of the UlkenMynzhylky riverbed; however, part of the debris flow continued further, entering the Left Talgar River. On the same day, a small-scale debris flow occurred in the area of Lake №19 (Left Talgar) due to the collapse of moraine ground [3,6, 8].

18.07.1970. In the basin of the Left Talgar River, a mudstone flow was formed due to a breakthrough inside the moraine waters [6].

12.07.1971. As a result of Lake №18 (volume 40-50 thousand m^3) rupture, mud(stone)flow was formed in the upper reaches of the Left Talgar River. The lake rupture occurred through a 200-300 m ice dam. The maximum flow rate of the mudflow reached 100-150 m^3/s [6,11].

15.07.1973. In the Left Talgar River basin, a mud(stone)debris flow formed due to the discharge of water from Lake №6, located on the moraine of the TEU-Severny Glacier. According to V.I. Shusharin and I.N. Markov, the lake's basin is situated on the glacier moraine, and its bottom consists of loose clastic material, with buried ice at a depth of 1.0-1.5 meters. On July 15, a grotto formed in the lake's lintel, allowing the lake to discharge a volume of 24,000 m^3 with flow rates sufficient to generate a mudflow. Data from KazHydroMet indicated that the maximum flood flow rate was 20-30 m^3/s. The debris flow had a maximum flow velocity of 8 m/s, a mudflow mass density of 2300 kg/m^3, and a total mudflow volume of 210,000 m^3.

Subsequent mudflows with similar formation processes were observed on July 16, 18, and 19, and on August 29 and 30 of the same year. Despite the frequent recurrence of mudflows during the summer of 1973, the lake cofferdam remained intact. With the onset of the warm period in 1974, the lake began to fill again, reaching its maximum level by mid-July[8,11,12].

15.07.1974. As a result of the emptying of moraine Lake №6 (with a volume of 26,000 m^3) located under the TEU-Severny Glacier in the basin of the Talgar River, a mudflow of the 2nd-3rd category was formed. Following a brief cooling period on July 13-14, the air temperature began to rise, reaching a maximum of 18°C in the lake on July 15. By 15:20, the lake water began to discharge through the grotto, accompanied by a deafening noise that triggered rockslides on the slopes of the cofferdam and the downstream area.

The water flowing from the lake saturated the loose clastic material in the area, causing the mass to reach its fluidity limit and rush downward, gaining speed. As the mudflow passed through an area with gradients reaching 22°C, stones, mud dust, and sparks from the impacts of large boulders were ejected from the stream. Ten minutes after the onset of the mudflow, the channel at the exit from the source deepened by 3 meters. Two additional, less powerful mudflows followed the initial one. Subsequently, a post-mudflow flood with a discharge of up to 5-10 m^3/s was observed. The water level in the lake dropped by 2.5 meters as the cofferdam was eroded. Within 40 minutes of the mudflow's start, the lake had discharged approximately 20,000 m^3 of water[6].

21-22.07.1974. The mudflow was formed as a result of a new emptying of Lake №6 under the TEU-Severny glacier (Middle Talgar). After the lake breakthrough on 15.07.1974, landslide processes occurring because of melting of the exposed intramoraine ice led to the formation of temporary cofferdams and, consequently, to its new filling. On 21-22.07.1974 these temporary dams were destroyed. The breakthrough flood rushing into the source formed a mudflow, 2.5 times more powerful than the mudflow on 15 July. The mudflow lasted for 2 hours, its maximum flow rate reached 200-250 m^3/s [6,11,15].

02.08.1974. The third mudflow in 1974 was observed in the area of Lake №6 (Middle Talgar River basin). The largest mudflow discharge was estimated at 300 m^3/s, although water inflow from Lake №6 into the source did not exceed 30 m^3/s. One of the versions of the mudflow formation process is as follows: ‘The front part of the flow, moving along the unprocessed channel and experiencing greater resistance, slows down its movement, the rear part swells up on it. As a result, the power of the shaft is constantly increasing, reaching values tens of times higher than the flow rate of water entering the upper part of the centre’. According to information, on the Middle Talgar River during the summer months of 1973-1974 there were nine mudflow breakthroughs of the glacial lake under the TEU-Severny glacier, the maximum volume of which in all cases did not exceed 25 thousand m^3. The outbursts occurred underground through a 20-30 m thick cofferdam. The highest mudflow discharges reached 200-300 m^3/s [6,15].

21, 24.06.1976. The breakthrough of Lake №6 under the Turistov Glacier in the basin of the Left Talgar River formed mudflows[12,16].

10.07.1976. During the breakthrough of Lake №5 under the Kalesnika glacier through the ice tunnel in the basin of the Left Talgar River, a mudflow was formed. The volume amounted to 200 thousand m^3 [6,8,12,17].

21.06.1979. A mudflow was formed in the basin of the Left Talgar River, the cause of which was the breakthrough of a moraine lake near the Sporty Glacier through an underground grotto. The maximum flow rate of the breakthrough flood was 5-10 m^3/s. The breakthrough flood, passing through the steps of ancient moraine sediments, formed a system of incisions. Tentatively, the volume of mudflow discharge was estimated at 200.000,0-300.000,0 m^3, and the density of the mudflow mass was more than 2000 kg/m^3. The breakthrough of the moraine lake through the underground grotto is not related to general meteorological conditions (air temperature, precipitation, height of the zero isotherm, etc.). The mudflow destroyed 14 offices and outbuildings of the alpine camp. The average balance estimate of mudflow density at the initial volume of the breakthrough flood of 87 thousand m^3 is 1800 kg/m^3. Apparently, the real density of the mudflow mass could reach 2000 kg/m^3[10,13,14].

August, 1983. Due to hot dry weather, small localised mudflows were observed from the areas of modern moraines in the basin of the Left Talgar River.

16.06.1984. In the basin of the Left Talgar River, a small category 3 mudflow was formed due to a large inflow of meltwater from the Kalesnik Glacier into Lake №5 and its subsequent emptying (according to observations by Kazselezaschita). According to the data, the emptying took place through an open ice channel. The volume of flood was 200 thousand m^3. 14.07.1989 on the Middle Talgar river on the background of heavy rainfall formed mudflow category 3 with a flow rate of 4.0-6.0 m^3/s. The cause of the outburst was slope slumping at the Starayaadit (moraine at the Yubileyny glacier). The crossing of the Middle Talgar River was washed away by the flashflood flow [16,12,17].

07.07.1990. In the upper reaches of the Middle Talgar River, as a result of the breakthrough of the moraine lake near glacier №162 (Yubileyny) with a volume of 5-7 thousand m^3, a mud(stone)debris flow of the 3rd category was formed with a maximum flow rate in the area of the breakthrough of 100-120 m^3/s. The debris flow wave spread in the channel of the Middle Talgar River. During the day there were 17 mudflows with flow rates from 15 to 100 m^3/s. In the Talgar River has passed flash flood category 3 with a maximum flow rate of 42 m^3/s.

15.07.1990. In the upper reaches of the Middle Talgar River, a 2ndcategory mudflow with a discharge of 80 m^3/s was recorded, the cause of which was the collapse of the slopes of the debris field of Bezymyanny spring stream against the background of heavy precipitation.

16-24.07.1990. As a result of impulse discharges of the lake under the Bezymyannyi glacier (Middle Talgar River) from 16 to 24 July, mudflows were registered.

06.07.1993. At 9:20 a.m., according to the Kazselezaschita service post, a mud(stone)debris flow of the 1st category formed in the basin of the OrtaTalgar River due to a lake outburst near the Bezymyannyi Glacier. This event was unrelated to the high-temperature background, intensive snow melting, or heavy precipitation typical of the current hydrometeorological situation. The breakthrough of Lake №9 resulted from the opening of intramoraine runoff channels, with the lake's surface being 60% covered by floating snow masses.

The mudflow began on the ledge of the modern moraine, but the primary collection of loose clastic material occurred lower down, in the debris center formed on the steep ledge of the older moraine. The mudflow entered the Middle Talgar River channel 1.5 km downstream of the Alplager gauging station (the former Talgar mountaineering base). During the mudflow formation, which lasted for 7 hours, several large and over a dozen small waves were recorded in the debris center. Visual estimates by an observer, located at a considerable distance (more than 500 meters), suggested that maximum flow rates approached 1000 m^3/s.

At the time of the breach, the lake basin contained slightly more than 100,000 m^3 of water. According to marks left in the channel, the maximum flow rate during the breakthrough did not exceed 10-15 m^3/s. However, this was sufficient to form a mudflow at the center's outlet, which surpassed the characteristics of a water flood by two orders of magnitude[10,18,19].

20.07.1993. In the basin of the Middle Talgar River in the mudflow incision under the Bezymyannyi Glacier, small mudflows with flow rates up to 15 m^3/s (3rd category) were observed as a result of the collapse of the sides, which remained significantly unstable after the mudflow of 06.07.1993.

24.06.1994. On the Middle Talgar River, as a result of collapse of the mudflows under the Bezymyannyi Glacier against the background of high temperatures and intensive snowmelt, a large post-mudflow phenomenon was observed - a mudstone flow of the 2nd category with a flow rate of up to 300 m^3/s.

21.06.1995. In the left tributary of the Middle Talgar River, at an altitude of 3700-3300 meters, a 2nd category mudstone debris flow occurred. The absence of apparent hydrometeorological triggers suggested that the primary mudflow-forming factor was the traditional collapse of the sides of the source area. Additionally, the hypothesis of small seismic shocks, recorded with an epicenter in the area, influencing the activation of mudflow forming processes, was considered. This hypothesis remained accepted even after an aerial survey of the Talgar River basin. However, ground surveys later suggested that the main cause was the breakthrough of the upstream moraine lake №9.

According to A.F. Prodan, a Kazselezaschita specialist who visited the area on June 22, the lake emptied due to the opening of a grotto at its bottom. Approximately 9.6 thousand m^3 of water, present in the lake before the mudflow, drained underground. The maximum flow rate of the debris flow was estimated at 150-180 m^3/s, with an average velocity of 5-6 m/s. During the mudflow movement, about 50 meters of pipeline were damaged, disrupting the water supply to Talgar town, a pipe bridge was destroyed, and 150 meters of motorway were swept away [Kazselezaschita data].

11.08.1996 г. On the frontal part of the modern moraine under Aristov Peak (Left Talgar) due to intensive melting of snow and glaciers against the background of high air temperature, the intraglacial capacity ruptured and a 3rd category mudflow was formed. As a result, an incision up to 1200 m long was formed in the moraine, from which about 300 thousand m^3 of loose clastic material was discharged. The mudflow at the confluence with the Left Talgar River was transformed into a sediment flood with flow rates of 3-5 m^3/s and a significant increase in water turbidity (up to 4 points). **09, 10, 15, 24.07.1997.**In the upper basin of the Sol Talgar River, mud(stone)mudflows formed in the mudflow gully under Aristov Peak were recorded:**09.07** – in a left incision in the moraine; **15.07** – as a result of an intraglacial outburst; **24.07** – as a result of moistening and collapse of the hearth sides. The loosened clastic material became fluid and transported along the bed of the hearth before reaching the bed of the Left Talgar River, where it manifested itself as a post-settlement flood.

07-08.08.1997. Two mudflows, each with a volume of 500 m^3, were recorded in the mudflow incision beneath Aristov Peak. The mudflow masses were deposited before reaching the bed of the Left Talgar River. On August 13, 1997, a large section of the slope in the mudflow incision beneath Aristov Peak collapsed, blocking the channel. This caused a temporary decrease in flow along the trench, leading to the accumulation of water and its subsequent breakthrough. On August 14, two category 3 mudstone outbursts occurred from the mudflow incision, with volumes of 1200 m^3 and 900 m^3, respectively.

The mass of the first mudflow did not reach the bed of the Sol Talgar River by 50 meters, while the mass of the second mudflow remained at the mouth of the source. Subsequently, a post-mudflow flood with flow rates ranging from 2 to 4 m^3/s passed through the area. At the BolshayaPolyana gauging station on the Left Talgar River, an increase in discharge by 1.5 m^3/s and turbidity up to 3 points was recorded. Additionally, on the Talgar River at the "Talgar-stage" gauging station, a slight increase in flow (up to 0.5 m^3/s) and turbidity (3rd category) was observed 1.5 hours later.

31.07.1999. In the basin of the Left Talgar River against the background of heavy precipitation in the centre under Aristov Peak, local mudstone mudflows of the 3rd category were observed, which reached the bed of the Left Talgar River, causing an increase in water turbidity.

09.07.2000. A mudstone flow of the 3rd category was formed in the mudflow under Aristov Peak. Along the bed of the Left Talgarriver bed was affected by a sediment-water flow of the 3rd category.

23.07.2003. On the Left Talgar River, mud(stone)flows of the 3rd category were observed from the mudflow center near Aristov Peak. The bottom of the mudflow incision was deepened by 5-7 meters after the mudflow event. Similar to previous years, part of the mudflow turned left and was deposited atop old sediments, while another part flowed straight ahead, almost perpendicular to the Left Talgar River's bed, blocking it and forming an extensive field of boulders, pebbles, and sand. The volume of the mudflow material was approximately 300,000-500,000 m^3, and the riverbed was completely obstructed for 800-900 meters, resulting in the absence of surface runoff in this area.

The temporary accumulation of water upstream of this dam led to its eventual failure and a significant increase in water discharge. Both the Left Talgar River and the Talgar River subsequently carried a substantial sediment load. The Talgar River experienced a sediment-water flow of the 3rd category. At the "Talgar-stage" gauging station, a flow rate of 31.5 m^3/s was recorded. Due to the overflow and destruction of the irrigation channel in the Talgar River bed, several dachas on the left bank were flooded. The high turbidity left approximately 28,000 residents of Talgar, Almalyk, Kyzyl-Kairat, Belbulak, Berlik, Taldybulak, and Amangeldy without drinking water.

17.08.2003. In the upper reaches of the Middle Talgar river (in the area of the Shokalsky glacier), during intense melting of the glacier, a moraine collapsed. The resulting mudflow did not reach the river bed.

17.07.2014. In the river basin Middle Talgar experienced a 2nd category mudflow. The mudflow was formed as a result of the breakthrough of a thermokarst moraine lake located on a young ice-saturated moraine at an altitude of 3420 m above sea level, under the Solnechny glacier.

This lake already broke through in 1993, which led to the formation of a mudflow with a volume of 2 million m^3 with a maximum flow rate of 1340 m^3/s. In 2014, the lake's outburst was preceded by rains and increased temperatures in the highlands. The flow rate of the mudflow in Middle Talgar and after its confluence with on Talgar was 50-80 m^3/s. The mudflow flowed along the riverbed in waves, rolling boulders and stones. As the flow approached the dam, large fractions of the mudflow mass were deposited. Approximately 300,000 m^3 of mudflow masses have accumulated in the mudflow trap bowl [KazSelezaschita data].

25.07.2015. At 13:55, during an aerial survey over the Ile Alatau Ridge, a mudflow was recorded originating from under glacier №105 "Komsomol" in the Left Talgar River basin. The mudflow discharge occurred in pulses with flow rates of 5-10 m^3/s, and the mudflow mass flowed into the main channel of the Left Talgar River, resulting in a mudflow flood. At the Bolshaya Polyana gauging station, the water flow of the Left Talgar River increased by 4 m^3/s. By 16:10, the flow reached the dam site on the Talgar River, with a flow rate of 29 m^3/s.

National Methods for Assessing the Hazards and Risks of Debris Flows from Glacial Lake Outbursts.

Moraine lakes have remained and continue to be poorly studied in terms of stationary and systematic limnological research. To better understand and assess the breach hazard of moraine lakes, research is conducted to determine the geological, engineering-geological, geomorphological, glaciological, and hydrometeorological factors affecting the mudflow risk in moraine-glacial complexes.

The primary causes of high-altitude lake breaches are considered to be: the destruction of moraine embankments (due to the melting of channel sediments, collapse of embankments, etc.), leading to the formation of powerful water flows; breaches through intra-moraine drainage channels via funnels, grottoes, which result in the discharge of water onto the lake embankment, below the modern moraine, or at a significant distance from the lake beneath the modern moraine.

Depending on the condition of lake basins, outburst-hazardous lakesare classified into the following categories: stationary, non-stationary, developing, degrading, and temporarily empty basins.

Kazakhstani scientists, including Keremkulov V.A., Plekhanov P.A., Medeu A.R., Kirenskaya T.L., Kassenov M.K., Zapparov M.R., and others, have developed criteria for assessing the breach hazards of moraine lakes over the years.

Most researchers classify lakes into three levels of breach hazard:

- Non-hazardous: Lakes that do not present significant risk of breach under current conditions.
- Potentially hazardous: Lakes that have the potential to breach under certain conditions or if specific risk factors are met.
- Hazardous: Lakes with a high likelihood of breaching due to existing conditions and risk factors.

Non-hazardous lakes are those with either a very small volume or a very stable dam. **Potentially hazardous lakes** are those with volumes greater than 10,000 cubic meters and an unstable dam. **Hazardous lakes** are non-stationary lakes with rapidly changing water levels, where the volume exceeds 100,000 cubic meters during the summer and is impounded by an unstable dam.

The primary criteria for assessing the breach hazard of moraine lakes have been developed based on the experience of Kazselezashita, data and materials from JSC "Institute of Geography and Water Security," other scientific literature, and conducted research. The developed criteria for the breach hazard of moraine and glacial lakes at Satbayev University are presented in Tables 4, 5, 6, 7, and 8.

The State Agency "Kazselezashita" remains the only specialized unit not only in the Republic of Kazakhstan but also in the CIS countries, responsible for engineering protection and prevention against mudflows, snow avalanches, landslides, and rockfalls, as well as for mitigating their consequences. It also ensures the functioning of relevant monitoring and warning services (monitoring hazardous phenomena) and performs the functions of a state customer for work and services related to the protection of populations and territories from hazardous natural phenomena.

Previously developed methods for determining breach hazard criteria categorized glacial lakes into three levels of hazard. Based on research by specialists from Kazselezashita and Satbayev University, new criteria have been developed, now divided into five categories of breach hazard for moraine-glacial lakes. These revised criteria are considered the most suitable and optimal for assessing the breach hazard of moraine-glacial lakes.

The new categories include:

1. "**Highly Hazardous Lake**": This category applies to moraine lakes where the risk zone includes more than 50 people or a strategically important facility, particularly in the absence of mudflow protection engineering structures.

2. "**Developing Lakes**": Given the recent intensification of thermokarst processes on modern moraines and the significant increase in the number of moraine-glacial lakes, this category allows for early monitoring of lake growth dynamics and subsequent assessment. This enables timely preventive measures to prevent the lake from reaching hazardous levels.

These categories facilitate the monitoring of lake dynamics at an early stage and the implementation of preventive measures to avert dangerous growth. Such work has been conducted in the early stages for lakes in the river basins of Aksay, Kargaly, Talgar, and Korgas.

To assess the breach hazard of moraine lakes, the evaluation was conducted within the complex of "glacier-moraine-lake" based on existing scientific literature and characteristics of recent mudflow events. The following indicators were used as criteria for evaluating lakes at this stage:

- **Lake Condition**: Type of lake (stationary or non-stationary), lake volume, filling regime, lake basin, runoff, and drainage channel.
- **Lake Dam Condition**: Composition of dam materials (e.g., loose debris, thawed and frozen soils, ice lenses), dam parameters (height, width, length), and overall state of the dam.
- **Moraine Condition**: Settlements, cracks, thermokarst depressions, traces of micro-mudflows and lake breaches, and other relevant features.
- **Moraine Escarpment Condition**: Parameters, general state, and lake position relative to the escarpment.
- **Glacier Condition**: Type, size, and lake position relative to the glacier.

Additional criteria for assessing hazard include:

- **Lake Location**: Elevation, exposure, river basin area, number of glaciers, and other relevant factors.
- **Potential Glacier Collapse**: Risk of collapse of the terminal moraine of the glacier or significant ice masses from the glacier, leading to the overflow of lake water.
- **Potential Landslide**: Risk of soil mass collapse from nearby slopes into the lake basin, causing subsequent water overflow from the lake.
- **Rapid Refilling**: Sudden refilling of the lake basin or rapid filling of previously empty basins and significant depressions on the glacier moraine.
- **Water Level Fluctuations**: Abrupt changes in water level (spikes) related to the pulsation of subglacial drainage during periods of intense glacier ablation.
- **Increased Outflow**: Rise in lake water outflow with mudflow-forming discharge rates.
- **Micro-Mudflows and Erosion**: Presence of micro-mudflow traces and "backwash" erosion in the drainage channel.
- **Channel Steepness**: Steepness of the drainage channel.

Table 4. Criteria for <u>**highlyoutburst-hazardous**</u> moraine lakes

<table>
<tr><th>Object</th><th colspan="6">Specifications</th></tr>
<tr><td rowspan="3">Lake</td><td>Type</td><td>Volume</td><td>Filling mode</td><td>Basin</td><td>Runoff</td><td>Runoff channel</td></tr>
<tr><td>Periodically filled</td><td>More than 40 thous. m^3</td><td>Sudden filling of a previously empty basin in the current year (at the beginning of a mudflow hazardous season)</td><td>Steep sheer sides of the runoff channel and lake basin
Areas with exposed buried ice.
Bottom slope towards the bulkhead</td><td>Absent</td><td>Not detected</td></tr>
<tr><td>Stationary</td><td>More than 40 thous. m^3

Inmost depth at the bulkhead or in the central part</td><td>Intensive growth in volume over the past 2-10 years - (from tens to hundreds of thousand m$^{3)}$</td><td>Steep sheer sides.
Areas with exposed buried ice.
Bottom slope towards the bulkhead</td><td>Partially superficial (over a short distance)

Intra soil</td><td>Easily eroded

Easily blocked by the collapse of soil, ice, snow</td></tr>
<tr><td rowspan="2">Lake bulkhead</td><td>Composition</td><td>Sizes</td><td colspan="4">Condition</td></tr>
<tr><td>Frozen breccia
Ice</td><td>Less than 10 m in width</td><td colspan="4">Soil subsidence. Voids, grottoes.
Superficial runoff. Leakage water outlets to the surface in the tail bay of the bulkhead.</td></tr>
<tr><td rowspan="2">Moraine</td><td colspan="6">Condition</td></tr>
<tr><td colspan="6">Presence of traces of the local and micro mudflows passage.
Cracks, subsidence, sinkholes, grottoes, thermokarst funnels with distinct water supply runoff channels.
Significant watering of the moraine.</td></tr>
<tr><td rowspan="2">Moraine ledge</td><td colspan="2">Parameters</td><td colspan="2">Condition</td><td colspan="2">Location of the lake relative to the moraine ledge</td></tr>
<tr><td colspan="2">Height 10 m and more</td><td colspan="2">Heterogeneity of particle size distribution
Intrasoil water outlets
Landslides, landslide funnels
High water cut</td><td colspan="2">Close (no more than 300m)</td></tr>
<tr><td rowspan="2">Glacier</td><td>Type</td><td>Sizes</td><td colspan="4">Location of the lake relative to the glacier</td></tr>
<tr><td>Valley
Hanging</td><td>0.5 km^2 and more
About 0.25 km^2</td><td colspan="4">Adjacent or at a distance of no more than 0.5 km</td></tr>
<tr><td rowspan="2">Risk zone</td><td colspan="6">with the presence of people located in the mudflow risk zone with a population of more than 50 people</td></tr>
<tr><td colspan="6">lack of engineering mudflow protection structures</td></tr>
</table>

Table 5. Criteria for **<u>outburst-hazardous</u>** moraine lakes

Object	**Specifications**					
Lake	***Type***	***Volume***	***Filling mode***	***Basin***	***Runoff***	***Runoff channel***
	Periodically filled	More than 40 thous. m^3	Sudden filling of a previously empty basin in the current year (at the beginning of a mudflow hazardous season)	Steep sheer sides of the runoff channel and lake basin Areas with exposed buried ice. Bottom slope towards the bulkhead	Absent	Not detected
	Stationary	More than 40 thous. m^3 Inmost depth at the bulkhead or in the central part -	Intensive growth in volume over the past 2-10 years - (from tens to hundreds of thousand m^3)	Steep sheer sides. Areas with exposed buried ice. Bottom slope towards the bulkhead	Partially superficial (over a short distance) Intra soil	Easily eroded Easily blocked by the collapse of soil, ice, snow
Lake bulkhead	***Composition***	***Sizes***	***Condition***			
	Frozen breccia Ice	Less than 10 m in width	Soil subsidence. Voids, grottoes. Superficial runoff. Leakage water outlets to the surface in the tail bay of the bulkhead.			
Moraine	***Condition***					
	Presence of traces of the local and micro mudflows passage. Cracks, subsidence, sinkholes, grottoes, thermokarst funnels with distinct water supply runoff channels. Significant watering of the moraine.					
Moraine ledge	***Parameters***	***Condition***	***Location of the lake relative to the moraine ledge***			
	Height 10 m and more	Heterogeneity of particle size distribution Intra soil water outlets Landslides, landslide funnels High water cut	Close (no more than 300m)			
Glacier	***Type***	***Sizes***	***Location of the lake relative to the glacier***			
	Valley Hanging	0.5 km ^{2} or more About 0.25 km^2	Adjacent or at a distance of no more than 0.5 km			

Table 6. Criteria for **<u>potential outburst-hazardous</u>** moraine lakes

<table>
<tr><th>Object</th><th colspan="6">Specifications</th></tr>
<tr><td rowspan="2">Lake</td><td>Type</td><td>Volume</td><td>Filling mode</td><td>Basin</td><td>Runoff</td><td>Runoff channel</td></tr>
<tr><td>Stationary (landslide, chocked)

Non - stationary</td><td>More than 50 thous. m^3
Inmost depth in the center or near the bulkhead</td><td>Slow volume growth over the past 10 years - (from tens of thousands of m^3)</td><td>Not steep sides.
Areas with exposed buried ice.
Weak bottom slope towards the bulkhead</td><td>Partially superficial (over a short distance)

Intra soil</td><td>Eroded

Possibly blocked by the collapse of soil</td></tr>
<tr><td rowspan="2">Lake bulkhead</td><td>Composition</td><td>Sizes</td><td colspan="4">Condition</td></tr>
<tr><td>Frozen breccia
Ice</td><td>More than 10 m in width</td><td colspan="4">Separate voids, grottoes.
Superficial runoff or leakage water outlets to the surface in the tail bay of the bulkhead.</td></tr>
<tr><td rowspan="2">Moraine</td><td colspan="6">Condition</td></tr>
<tr><td colspan="6">Minor subsidence, small cracks.
Traces of the micro mudflows passage,
Process of forming a runoff channel.
Average water cut.</td></tr>
<tr><td rowspan="2">Moraine ledge</td><td colspan="2">Parameters</td><td colspan="2">Condition</td><td colspan="2">Location of the lake relative to the moraine ledge</td></tr>
<tr><td colspan="2">Height is about 10 m</td><td colspan="2">Heterogeneity of particle size distribution
Individual landslides, landslide funnels
Average water cut</td><td colspan="2">At a distance of about 500m</td></tr>
<tr><td rowspan="2">Glacier</td><td>Type</td><td>Sizes</td><td colspan="4">Location of the lake relative to the glacier</td></tr>
<tr><td>Valley

Hanging</td><td>0.5 km^2 and more
About 0.25 km^2</td><td colspan="4">At a distance of more than 0.5 km</td></tr>
</table>

Table 7. Criteria for **non-outburst-hazardous** moraine lakes

Object	Specifications					
Lake	***Type***	***Volume***	***Filling mode***	***Basin***	***Runoff***	***Runoff channel***
	Stationary (landslide, tarn) Non - stationary	less than 40 thous. m^3 Inmost depth in the center or on the opposite side of the bulkhead.	Lack of volume growth over the past 10 years or degradation of the lake basin	Flat sides. Weak bottom slope towards the bulkhead	Partially superficial Intra soil	Not eroded There is no possibility of overlapping by soil collapse
Lake bulkhead	***Composition***	***Sizes***	***Condition***			
	Compacted soils	Less than 10 m in width	Superficial runoff is absent or insignificant. There are no leakage water outlets to the surface. Outcrops of bedrock are observed in the lake bulkhead.			
Moraine	***Condition***					
	Absence of subsidence and cracks. Lack of traces of the micro mudflows passage, The process of formation of the runoff channel has been completed or absent. Average or low water cut.					
Moraine ledge	***Parameters***		***Condition***		***Location of the lake relative to the moraine ledge***	
	Height less than 10 m		Heterogeneity of particle size distribution Individual landslides, landslide funnels Average water cut		At a distance of about and more than 500 m	
Glacier	Type	Sizes	Location of the lake relative to the glacier			
	Valley Tarn Hanging	less than 0.5 km^2	At a distance of more than 0.5 km			

Table 8. Criteria for **developing**moraine-glacial lakes

Object	Specifications					
Lake	***Type***	***Volume***	***Filling mode***	***Basin***	***Runoff***	***Runoff channel***
	Stationary (landslide, chocked) Non - stationary	More than 5 thous. m^3 Lake parameters 30x50 m with significant development potential	Intensive volume growth over the past 1-3 years to tens of thousands m^3)	Steep sides. Areas with exposed buried ice. Steep bottom slope towards the bulkhead	Partially superficial (over a short distance) or the complete absence of runoff Intra soil	Eroded or unorganized runoff channel without a laid natural armoring channel Possibly blocked by the collapse of soil, ice.

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Kazselezaschitaobservationmaterials

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