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DISASTROUS DEBRIS FLOWS CONNECTED WITH GLACIAL PROCESSES AND DEFENSE METHODS AGAINST THEM IN KAZAKHSTAN

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ABSTRACT

Due to climate warming which came after the ending of the Small glacial age, surface and subsurface reservoirs started to form on the mo - raine-glacial complexes of the northern slope of the Zailiysky Alatau Mountain Range. Breakout of these reservoirs led to disastrous debris flows in the middle of the 20th century. Up to 60s of the 20th century rainfall-caused debris flows with rare frequency were considered to be of main danger and construction of large check dams forming debris-flow reservoirs was assumed as a basis of defence strategy against debris flows. The sharp activation of debris flows connected with glacial processes required revision of the existing defence strategy against debris flows. That is why designing and building the small reservoirs for detention of glacial outburst water in the high-mountain zone and preventive measures aimed at emptying lakes on the moraine-glacial complexes started.

Key words: *moraine lake, debris flow, preventive measures*

INTRODUCTION

The Zailiysky Alatau is one of the northern ranges of the Tien Shan Mountain system (Fig. 1). This mountain range is characterized by the high debris-flow activity. Rainfall-caused debris flows and debris flows connected with glacial processes have the greatest activity. Debris flows connected with earthquakes take place very rarely. However these debris flows have the greatest scales.

rarely. However these debris flows have the greatest scales. Debris-flow activity connected with glacial processes is defined by scales of glaciations and reaches its maximum in the phase of their degradation. The area of glaciations in the Zailiysky Alatau makes about 262 km^2 (Kudekov (ed), 2002). During degradation of glaciations the surface and subsurface reservoirs are formed. Their breakout leads to formation of debris flows. During degradation of glaciations under climate warming rainfall-caused debris flows will become more dangerous than debris flows connected with glacial processes already in the 21st century (Yafyazova,

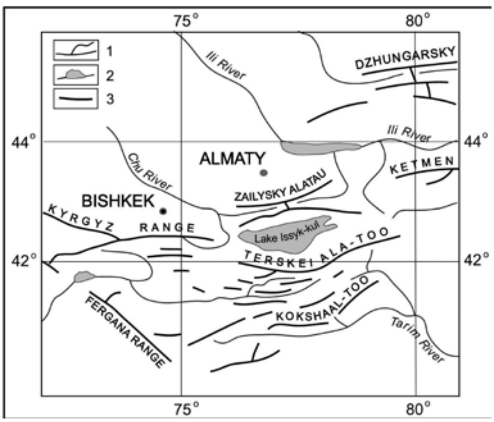

Fig. 1 - The scheme of Tien Shan orography region 1 – rivers; 2 – lakes; 3 – ranges

2003; Yafyazova, 2007a; Yafyazova, 2009).

The settlements (including Almaty city) with the total population of about 2 million inhabitants are located in the foothill zone of the northern slope of the Zailiysky Alatau. In this connection the defense against debris flows plays an important role in the sustainable development of the Republic of Kazakhstan. In order to decrease damage caused by debris flows, in the majority of river basins of the northern slope of the Zailiysky Alatau debris-flow-defensive constructions were built. Preventive measuresare limited only preventive emptying debris-flow dangerous lakes.

DEBRIS FLOWS CONNECTED WITH GLACIAL PROCESSES ON THE NORTHERN SLOPE OF THE ZAILIYSKY ALATAU IN THE 20TH CENTURY

Debris flows connected with glacial processes formed due to breakout of surface and subsurface reservoirs of moraine-glacial complexes. In the course of degradation of glaciations the sizes of these reservoirs increase. On the northern slope of the Zailiysky Alatau the degradation of glaciations began after the Small glacial age. Formation of the large lakes on the moraine-glacial complexes, which became debris-flow dangerous, was recorded at the beginning of the 20th century (Vinogradov, 1977). The basins of the Issyk, Malaya Almatinka and Bolshaya Almatinka Rivers are characterized by the most debris-flow activity connected with glacial processes in comparison with other river basins (Fig. 2).

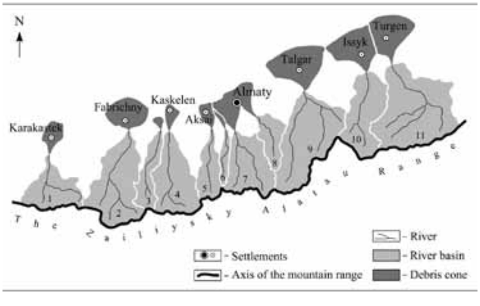

Fig. 2 - The schematic map of the northern slope of the Zailiysky Alatau The river basins: 1 – Karakastek; 2 – Uzunkargaly; 3 – Chemolgan; 4 – Kaskelen; 5 – Aksai; 6 – Kargalinka; 7 – Bolshaya Almatinka; 8 – Malaya Almatinka; 9 – Talgar; 10 – Issyk; 11 – Turgen. During 1959-1962 the underground channel in the lake

The first disastrous debris flow, caused by breakout of lake No.17 located on the Zharsay glacier (the Issyk River basin), happened on 6 July 1958. The volume of debris flow made 4 million m3 (Popov, 1981). The breakout of this lake happened through a underground channel formed in the lake dam. The debris flow did not cause the large damage, as it partially deposited in lake Issyk located in the middle-mountain zone. Debris-flow mass was mainly deposited on the sites with slight slope of the Issyk River valley and the Issyk River debris cone adjoining to lake Issyk (Fig. 3).

During 1959-1962 the underground channel in the lake dam was functioning, therefore the hollow of lake No.17 located on the Zharsay glacier was not filled by water. In autumn and winter 1962- 1963 the underground channel was blocked and the hollow of lake No.17 was filled by water again. On 7 July 1963 the disastrous breakout of this lake happened through the same underground channel, as it was on 6 July 1958 (Zems, 1976). The water flow came out to the surface outside the lake dam at a distance of about 100-150 m from this lake. Then it partially went into a underground channel. The water flow moving on the surface rushed down in a torrent gully. There it was transformed into a debris flow. The water flow moving on the underground channel wetted a moraine and the landslide was formed on the frontal part of moraine. It transformed into a debris flow and embodied with the debris flow formed in the torrent gully. Further the debris flow moved along the Zharsay River valley (it is

Fig. 3 - The path of debris flows in 1958 and 1963 in the Issyk River valley. 1 – the hollow of lake No.17 on the Zharsay glacier; 2 – the torrent gully; 3 – the Issyk river; 4 – lake Issyk

a tributary of the Issyk river), and then it moved along the Issyk River valley down to lake Issyk (Figg. 3, 4).

The debris flow was entering into lake Issyk during 4 hours. Formation of waves on the surface of lake Issyk together with increase of water level led to destruction of the lake dam. Emptying of the lake Issyk with the volume of more than 18 million m3 lasted for a few hours. The maximal discharge of outburst water was estimated at 500-800 m3/s (Duysenov, 1971). The 1963 debris flow had disastrous consequences. At the minimum, 54 men, who had rested near lake Issyk, were killed. The damage was large. The maximal discharge of debris flow made 7-12 thousand m^3/s, the volume was 5.8 million m3, the density of debris-flow mass made approximately 2400 kg/m3 (with the average density of solid component of debris flow of 2650 kg/m3, the volumetric concentration makes 85%) (Zems, 1976). The debris flow deposited basically in lake Issyk.

After the 1963 debris flow it became obvious, that debris flows connected with glacial processes could be disastrous and cause the large damage to settlements located on the foothill plain adjoining the northern slope of the Zailiysky Alatau. That is why the government of the Republic of Kazakhstan made the decision to speed-up designing and building of a check dam to defend Almaty city against debris flows. The dam formed a debris-flow reservoir with the volume of 6.2 million m^3 in the Medeo tract (Khegay, 1988). In 1976 the volume of debris-flow reservoir was increased up to 12.6 million m^3.

In autumn and winter 1976-1977 the underground channel in the lake dam was blocked again. It led to filling the hollow of lake No.17 by water. During spring and summer melting of snow and ice the water level in the lake No.17 increased up to the value, at which water overflowed through the lake dam. The situation could be aggravated with opening of the underground channel. It could lead to formation of a disastrous debris flow. As the dam of lake Issyk was destroyed in 1963, the debris flow, which could form due to breakout of the lake on the Zharsay glacier, could reach Issyk town unhindered. It would lead to the large damage. The decision about preventive emptying lake No. 17 was made. This emptying prevented formation of a disastrous debris flow (Mochalov *et alii*, 1980a; Mochalov *et alii*, 1980b).

Another river basin, with sharp activation of debris flows connected with glacial processes in the 20^{th} century, was the Malaya Almatinka River basin. The first debris flow connected with glacial processes occurred in this basin on 20 August 1951. It formed due to breakout of lake No.2 on the Tuyuksu glacier (Cherkasov, 1953). The breakout of the lake happened through an underground channel. At that time the lake was relatively small by volume (about 20 thousand m3). As the formed debris flow did not cause the large damage, the conditions of its formation were not studied (Duysenov, 1971; Vinogradov, 1977).

On 7 August 1956 in the Malaya Almatinka River basin a debris flow was formed due to breakout of a subsurface reservoir located into the Tuyuksu moraine-glacial complex. The volume of gushed water was estimated at 1.5-2 million m^3 (Vinogradov, 1977). The formed debris flow was accompanied by a large and long postdebris- flow flood. At that time Almaty city was not protected by the check dam but was not damaged because the outburst water had the discharge of about 30 m^3/s only in its initial phase (Vinogradov, 1977). Fortunately, the water ran out of the subsurface reservoir with the relatively small gradually decreasing discharge, and therefore the debris flow deposit did not reach Almaty city. Nevertheless, it caused other damage.

Fig. 4 - The torrent gully situated into the ancient moraine of the Zharsay glacier. 1 – the torrent gully; 2 – the landslide recess (right)

By 15 July 1973 (the date of formation of a debris flow) the volume of lake No.2 on the Tuyuksu glacier increased up to 260 thousand m^3. The water level in the lake was sustained constant owing to water overflow over the lake dam. The discharge of water over the lake dam sharply increased, most probably, as a result of drawing the lake dam caused by thawing of buried ice. The opening in the lake dam increased quickly because of erosive water flow (Fig. 5).

The maximal discharge of outburst water was about 350 m^3/s. The volume of water which poured out from the lake made about 224 thousand m3. Debris-flow mass, formed on the frontal part of modern moraine, decayed on the glacial-carved valley on the path to a dam in the Mynzhilki tract. As the volume of reservoir formed b the dam was only about 10% of the volume of the glacial outburst water, the dam was destroyed within 3 minute (Fig. 6). Having breached the dam, the water flow rushed down in a torrent gully in the ancient moraine. The debris flow passed 8-kilometer to the check dam in the Medeo tract in 12-13 minute (its velocity was 10- 11 m/s). It deepened the torrent gully by 12-15 m (in some places by 40 m). The debris flow destroyed two open-type dams in its way (Fig. 7). The debris-flow 15-meter high wave entered the debrisflow reservoir in the Medeo tract with the discharge of about 10 thousand m^3/s (Fig. 7). The volume of debris flow made 3.8 million m^3, and the average density of debris-flow mass was 2400 kg/m^3 (with the average density of solid component of debris flow of 2650 kg/m^3, the volumetric concentration is 85%) (Vinogradov, 1977). It is important to note that in its way the debris flow entrained along in debris-flow process not only by loose rocks, but also water of various genesis, the main part of which made interstitial water equal to 455 thousand m^3. The volume of interstitial water entrained along with soil in the debris flow 2 times exceeded the volume of outburst water from the lake.

The 1973 debris flow in the Malaya Almatinka River basin caused the large damage. Due to filled debris-flow reservoir by debris-flow mass by 60% Almaty city was unprotected against debris flows for a few years (Fig. 8). The dam kept the debris flow and

Fig. 5 - Lake No.2 after its breakout in 1973

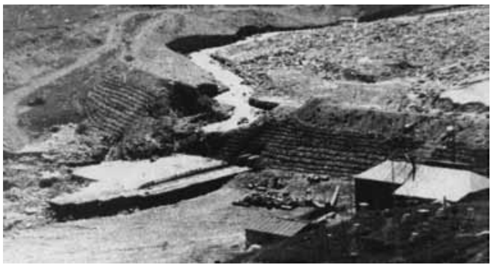

Fig. 6 - The dam opening after the 1973 debris flow in the Mynzhilki tract

Fig. 7 - The open-type dam destroyed by the 1973 debris flow

thereby it saved the eastern part of Almaty city from destruction. Unfortunately, 70 men who were upstream of the check dam were killed (Khegay, 1988; Yafyazova, 2007b).

According to the technical report, measuring characteristics of the 1973 debris-flow deposits surface in the debris-flow reservoir in the Medeo tract, showed that at a distance of 350 m from the dam (the average depth of 50 m) the slope of debris-flow deposits surface did not exceed 0.3º; at a distance of 350-450 m (the average depth of 40 m) it was close to 0.7º; at a distance of 450-550 m (the average depth of 30 m) it increased nearly to 1º and only at the next following 200 m (the average depth of less than 20 m) it increased almost to 2º. The fact that debris-flow deposits surface forms slight slope while depth exceeds tens of meters in the debris-flow reservoir is of the great importancewhen debris-flow reservoirs are designed (Fig. 9).

The 1973 debris flow confirmed the results of experiments on artificial replication of debris flows carried out by the Kazakh Research Hydrometeorological Institute in the Chemolgan River basin in the period 1972-1978 (Stepanov & Stepanova, 1991).

It was found out, that mixture of debris-flow mass during movement of debris flow was kept up to values of concentration of solid component in debris-flow mass, much more exceeding values of concentration known earlier (Stepanov & Stepanova, 1991). Just being mixture, when the concentration of solid component in debrisflow mass is large, conditioned an opportunity of formation of debris-flow mass with the density of more than 2400 kg/m^3 (it is possible, when granulometric and mineralogical compositions of soils participating in debris flow-forming are similar to soils of ancient moraines in the Zailiysky Alatau).

On 19 August 1975 debris flow was formed due to breakout of lake No.14 located on the Kumbel glacier (the Bolshaya Almatinka River basin). The maximal discharge of debris flow did not exceed 160 m^3/s. The density of debris-flow mass reached 2500 kg/m^3 (with the average density of solid component of debris flow of 2650 kg/m^3, the volumetric concentration makes 91%) (Kirenskaya *et alii*, 1977). Owing to the high density of debris-flow mass the velocity of debris flow (the maximal depth of debris flow equal to 5.6 m) did not exceed 2 m/s. The traces of debris flow are shown in Fig. 10. For debris flows with the low velocity are characteristic the following: pronounced boundary of debris flow surface; the absence of an aerosol mud cloud above a debris flow; little skewing of the debris-flow surface at bends (Kirenskaya *et alii*, 1977).

On 3 August 1977 in the Bolshaya Almatinka River basin during preventive works on lake No.13 located on the Sovetov glacier breakout of the lake happened and disastrous debris flow was formed (Popov *et alii*, 1980). As a result of failure of the lake dam water with volume of 74.5 thousand m^3 was dis-

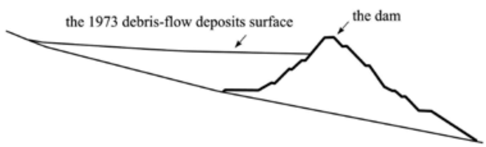

Fig. 9 - The 1973 debris-flow deposits surface in the reservoir whichformed by dam

Fig. 8 - The debris-flow reservoir filled by the 1973 debris-flow mass in the Medeo tract

Fig. 10 - Traces of the debris flow of 19 August 1975 in the Bolshaya Almatinka River basin

charged from the lake during 1 hour 25 minute. The average discharge of water through the opening in the lake dam was 15 m^3/s, and the maximal discharge of water exceeded 30 m^3/s (Fig. 11). The solid component of debris flow, formed on the modern moraine, was mainly deposited on the glacial-carved valley at a height of more than 3000 m a.s.l., located above a torrent gully. The liquid component of debris flow, containing in its composition the insignificant amount of suspended particles, entered the torrent gully.

The deepening the torrent gully and the collapsing its sides led to the outlet onto the day surface of numerous underground springs. It resulted in the significant increase of discharge and volume of debris flow on 3 August. On subsequent days numerous formation of debris flows with the relatively small volume took place as a result of instability of sides of the torrent gully. However short-term formation of debris flow with the maximal discharge of about 10 thousand m3/s took place on 4 August.

According to various estimations, over the period 3-31 August the total volume of debris flows varied from 2.4-3.2 million m^3 (Popov *et alii*, 1980; Osipova & Kazannikov, 1982) to 6 million m^3 (Yesenov & Degovets, 1979). Debris-flow events happened on 3-31 August 1977 in the Bolshaya Almatinka River basin caused the large damage, people were killed.

As a result of debris-flow events on 3-31 August 1977 researchers made up a conclusion that intense wetting (more than 15%) moraine can turn 1 m3 of water into 60 m^3 of debris-flow mass. Such ratio is applicable when wet soil is on yield stress, and granulometric and mineralogical compositions of soil are similar to soil of ancient moraines in the Zailiysky Alatau (Stepanova, 1989).

Fig. 11 - Lake No.13 after its breakout in 1977. 1 – opening in the lake dam; 2 – the hollow of lake

During the 20th century debris flows connected with glacial processes were formed also in the other river basins of the northern slope of the Zailiysky Alatau, but they had no disastrous character.

DEFENCE AGAINST DEBRIS FLOWS CONNECTED WITH GLACIAL PROCESSES

The necessity of defense against debris flows of Almaty city was realized in the second half of the 19th century (Khegay, 1988). The relevance of this problem was confirmed by the event of 1921 when the eastern part of Almaty city was destroyed; about 500 people were killed due to a rainfall-caused debris flow. As till 60s years of the 20th century it was considered, that rainfall-caused debris flows, which had rare frequency, represent the main danger, the construction of large check dams forming debris-flow reservoirs (with the volume of about 10 million m^3) was assumed as a basis of defence strategy against debris flows. The sharp activation of debris flows connected with glacial processes required revision of the existing defence strategy against debris flows. That is why designing and building the small reservoirs in the high-mountain zone (with the volume of about 200 thousand m^3) for detention of glacial outburst water and carrying out measures on preventive emptying lakes on the moraine-glacial complexes were begun.

In the period 1964-1966 the using siphons for maintenance of the safe water level in lake No. 2 located on the Tuyuksu glacier (the Malaya Almatinka River basin) is the beginning of preventive measures for prevention and mitigation of consequences of debris flows connected with glacial processes in Kazakhstan. Due to difficult servicing the siphons their work was stopped with the beginning of construction of the check dam in the Medeo tract. Preventive emptying surface reservoirs on the moraine-glacial complexes in the basins of the Issyk, Malaya Almatinka and Bolshaya Al-matinka Rivers became the following stage in the realization of preventive measures.

Preventive emptying lake No. 17 located on the Zharsay glacier (the Issyk River basin) in 1977 is the first successful experience in prevention of formation of disastrous debris flows connected with glacial processes in Kazakhstan. In 1977 the hollow of lake No. 17

was filled again by water. The hollow was filled and empted with formation of the disastrous debris flows in 1958 and 1963. As having surface overflow water through the lake dam was inevitable (in the lake the water level was increased by approximately 0.5 m pe day), and breakout of underground channel with the disastrous discharge of water could happen within the next few days, the decision was accepted to make use by the surface channels formed still in 1963 for controllable empting the lake. For this purpose the moraine soil was got out of the surfaces of channels. Having over - flow water on these channels led to their gradual deepening. The regulation of intensity of thawing of ice in the channels was carried out by cleaning of soil in the channels. As a result of the described measures it was possible to carry out controllable discharge water equal to more than 200 thousand m3 from lake and to ensure further spontaneous empting of 220 thousand m3 of water The average discharge of water through the lake dam made about 1.8 m3/s, and the maximal discharge was 6-8 m^3/s (Mochalov & Stepanov, 1980; Stepanov *et alii*, 2001).

By the beginning of August 1977 the moraine soil adjoining to the channel unfreeze due to land reclamation work and the thermal effect of water flow. On 3 August when the water level in the lake rising by 0.7 m relative to the natural overflow crest of channel the spontaneous destruction of embankment happened and a debris-flow process began directly on the lake dam. It led to disastrous empting the lake. An initial phase of destruction of the lake dam was not observed (Popov *et alii*, 1980; Stepanov *et alii*, 2001).

Preventive emptying lake No.9 located on the Bogatyr glacier (the Chilik River basin) was the most scale preventive measure. The Chilik River basin is located on the southern slope of the Zailiysky Alatau, the northern slope of the Kungey Alatau, and the eastern slope of the Chilik-Kemin cross connection. Lake No.9 is located at a height of 3460 m a.s.l. In 1985 before the beginning of preventive measure the lake was as long as 1,850 m, as wide as 670 m, with the average depth of 13.3 m and the maximal depth of 34.9 m. The area of water surface of the lake was 690 thousand m^2 and its volume was 9.3 million m^3. The lake dam was combined the frozen moraine soil and buried ice. The temperature of frozen moraine soil changed from 0 to -3.3 ºC at a depth from 3 to 10 m. In summer period, when the water level in the lake was maximal, water flow happened through the surface channel with the discharge to 29 m^3/s. The prevention of disastrous flood which (as it was considered) could formed during displacement of water from the lake due to the fast movement of the Bogatyr pulsative glacier was by the purpose of preventive emptying this lake. The evacuation channel was formed by explosion. The explosive was tamped in the holes, which were located along the planned evacuation channel at a depth of from 3 to 11 m. The total weight of an explosive was about 14 tons. As a result of explosion the frozen moraine soil and buried ice of about 10 thousand m3 was ejected from the lake dam. The gradual increasing the water discharge to 105 m^3/s was observed in the channel within 6 hours. Then the water discharge gradually decreased. The emptying lake No. 9 lasted about two days. The volume of the water was decreased by 6.2 million m3, the water level was lowered by 14.5 m. The evacuation channel was deepened by 15-20 m due to thermal and mechanical erosion, and its throat advanced into the lake by 200 m (Bizhanov *et alii*, 1998).

In 1997 lake No. 6 located on the Manshuk Mametova glacier (the Malaya Almatinka River basin) was recognized the most dangerous moraine lake on the northern slope of the Zailiysky Alatau. Preventive emptying this lake has a long history. In the second half of the last century some attempts for its preventive emptying were carried out for decreasing the volume of the lake to a safe water level. The first attempt for its emptying was carried out in the period 1976-1978, when the volume of the lake was about 40 thousand m^3. As a result of the performed work the volume of the lake was reduced to 36 thousand m^3 (Bizhanov *et alii*, 1998). The second attempt for its emptying was carried out in 1997. At this time the volume of the lake was about 190 thousand m^3. According to the technique of emptying the lake it was supposed, that decreasing overflow crest of channel on the lake dam by washing away and transporting moraine soil will be carried out by using water energy. It was supposed to carry out by discharges water from the lake by means of «soft (made of tarpaulin) and «rigid» (made of metal) gates. The shortterm discharges of water with the discharge of 10-12 m^3/s were formed by "soft" gate for destruction of stone riprap. The stone riprap was formed after every discharge water. The long-term discharges water with the discharge of 3-4 m^3/s were formed by «rigid» gate for deepening the channel. The non-observance of the technique led to formation of stone riprap, which the water flow with the discharge of 10-12 m^3/s could not destroyed. Due to the water level in the lake was lowered by 2.6 m in place of planned of 5 m.

During the past decades the preventive emptying of some debris-flow dangerous lakes was made in the other river basins of the northern slope of the Zailiysky Alatau. However these lakes had the small volumes and did not represent the large threat.

The building dams in the high-mountain zone for detention of water flows formed during breakout of moraine lakes is a very effective way for defence against debris flows connected with glacial processes in the Zailiysky Alatau. In the high-mountain zone the valleys are characterized relatively slight slopes and large width. The dam forming a reservoir for detention of glacial outburst water in the Mynzhilki tract at a height of 3000 m a.s.l. is an example of building dams in the high-mountain zone. The volume of reservoir is 230 thousand m3. On the efficiency this dam is equivalent to a dam forming a reservoir for detention of debris-flow mass with the volume of about 4 million m^3 and located at a height of 1700-1800 m.

DEBRIS-FLOW DANGER CONNECTED WITH GLACIAL PROCESSES AT PRESENT TIME

Due to global climate warming there is an intensive thawing of glaciers on the northern slope of the Zailiysky Alatau. For 35 years the area of glaciers decreased by 30% (Vilesov, 1997). The most likely, by the end of the 21st century in the Zailiysky Alatau the glaciers will disappear (Vilesov, 1997). However within the next decades the danger of formation of debris flows connected with glacial processes can even be increased. The existing methods for preventive emptying moraine lakes will allow to avoid the large material damage and to keep health and life of people. However the preventive emptying of moraine lake is not a unique way for prevention of debris flows connected with glacial processes. Existing experience of glacial monitoring allows to assert, that the prevention of occurrence and development of surface reservoirs on the moraine-glacial complexes is the most effective and safe way for prevention of debris-flow danger. Unfortunately, till now in Kazakhstan the due attention is not given to prevention of occurrence and development of lakes on the moraine-glacial complexes

At the present time the most dangerous lake in the Zailiysky Alatau is lake No. 6 located on the Manshuk Mametova glacier. Its volume is about 230 thousand m^3. According to existing estimations, the volume of debris flow, which can be formed during breakout of this lake, can exceed 10 million m^3. This is commensurable with the volume of the debris-flow reservoir which was constructed in the Medeo tract for defence against debris flows of Almaty city. The overflow of the debris-flow reservoir can lead to destruction of the eastern part of Almaty city.

Aforesaid concerns to dangerous surface reservoirs. At the same time subsurface reservoirs of moraine-glacial complexes are represented not the smaller danger. In Kazakhstan there are no methods for detection of subsurface reservoirs and their preventive emptying. So, the 1956 debris flow was formed the Malaya Almatinka River basin due to breakout of the subsurface reservoir located into the Tuyuksu moraine-glacial complex. If the total outlet water transformed into debris flow, no one dam constructed in the valleys of the northern slope of the Zailiysky Alatau by the present time could not check it.

As a reduction of sizes of moraine-glacial complexes due to climate warming in the Zailiysky Alatau rainfall-caused debris flows will become more dangerous than debris flows connected with glacial processes (Yafyazova, 2009).

DISCUSSION AND CONCLUDING REMARKS

The defence against debris flows of the settlements located on the foothill plain adjoining to the northern slope of the Zailiysky Alatau is based on the scientific consideration about debris flows in the middle of the last century. The results of researches carried out in the last decades testify to significant inconsistency of protection rate of these settlements to the real threats which debris flows create under the climate conditions in the 21st century (Yafyazova, 2009 Yafyazova, 2010). During recent decades the reality of global warming has been confirmed. For the Tien Shan region warming is causing significant decrease in the area and volume of glaciers, enhancing permafrost thaw, relocating the forest boundary along mountainsides to higher altitudes, increasing the number of glacial lakes and associated breakout floods, and increasing rainfall-induced debris flows activity. In this region, the defense strategy against debris flows is based on the frequency of rare, large debris flows typical under the climate conditions of the 19-20th centuries. Therefore, under global warming defensive measures based on the sizes of debris flows in the pas century will not provide reliable protection. The development of a defensive strategy against debris flows under climate warming is a prerequisite for the sustainable development of the Republic of Kazakhstan

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