СЕЛЕВЫЕ ПОТОКИ: катастрофы, риск, прогноз, защита

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The safety of city Telavi from the destructive effects of debris flow

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Abstract. In order to improve the safety of the population of the city of Telavi in the catchment area of the Telavis khevi River, scientific research was carried out to assess the risks of flooding of the territories of the city from anticipated floods and mudflows. In order to protect the population of Telavi from natural disasters caused by floods and mudflows formed in the Telavis khevi River bed and to assess the risks of flooded areas, scientific field and theoretical studies have been carried out, by means of which the erosion coefficient of mountain slopes, taking into account its main determinants, the volume of masses collapsed or dumped from mountain slopes in corresponding GPS coordinates are established and using mathematical modeling of the flow wave, the risk zones of flood and landslide inundated areas formed in the river channel in case of collapse of the natural barrier of 10 m height was established.

Key words: *the city of Telavi, population, natural disasters, safety, risk*

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Обеспечение безопасности города Телави от разрушительного воздействия селевого потока

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Аннотация. В целях повышения безопасности населения города Телави, расположенного на водосборной территории реки Телавис-хеви, проведены научные исследования по оценке рисков затопления территорий города ожидаемыми наводнениями и селями. В целях защиты населения города Телави от стихийных бедствий, вызванных наводнениями и селями, образующимися в русле реки Телавис-хеви, и оценки рисков затопления территорий проведены научные полевые и теоретические исследования, в результате которых установлен коэффициент эрозии горных склонов с учетом его основных детерминант, объем масс, обрушившихся или сброшенных с горных склонов в соответствующих GPS-координатах, а также с помощью математического моделирования волнового потока установлены зоны риска затопления территорий паводками и оползнями, образующимися в русле реки при обрушении естественного барьера высотой 10 м.

Ключевые слова: *город Телави, население, стихийные бедствия, безопасность, риск*

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Introduction

The territory of Telavi Municipality and Telavi itself geographically includes the river Alazani right bank and the northern slope of the watershed of Tsiv-Gombori Ridge (Fig. 1).

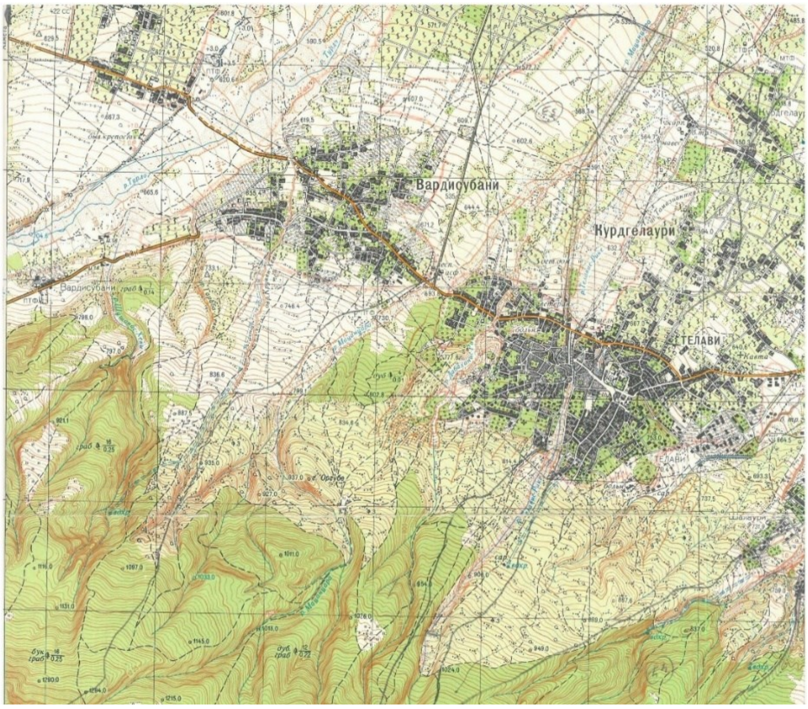


Fig. 1. Map of the River Telaviskhevi catch basin

From a geological point of view, the sloping depression of Alazani Valley is a very peculiar tectonic sinking structure, representing the remnant of a subsided foothill zone composed of Upper Jurassic and Cretaceous carbonate flysch, adjoining from the north to the Alazani Plain until the middle Pliocene and separated from the South Caucasus tectonic Block by a clearly shaped tectonic fault plane.

The general morphology of the Tsiv-Gombori Ridge is dominated by mesorelief created by water erosion, represented by deeply dissected narrow valleys, old peneplenised and typical kainotype flattened surfaces exposed by palaeotypic erosive-denudation processes and badland relief formed by erosion gullies is developed in the molasses deposits of the Ridge crest-side zone, as the hearths of mudflow processes formation and relief forms developed by landslide processes, which are an inexhaustible source of landslide formation and often lead to catastrophic landslides.

The northern slope of the Tsiv-Gombori Ridge, which borders the territory of Telavi from the south and is part of its area, creates a unique natural landscape that shapes the appearance of the city. The landscape and morphological peculiarity of this unique Ridge is due to its geographical location, complex geotectonic pattern of development and geological structure, the set of which has given the landscape morphology of the Ridge a special spectacular and cognitive aspect with its diverse paleo- and kainotypical relief morphological forms. The mid- and lower-mountain Tsiv-Gombori Ridge, on the other hand, is a watershed of the Alazani and Iori Rivers, which at the same time divides the Alazani Plain from the Iori Plateau.

According to the climatic zoning of Georgia (G. Chirakadze), the city of Telavi and its surroundings are located in the 6th climatic zone and occupy the Alazani Valley and foothills. The zone as a whole is characterized by moderate humidity, relatively warm winters and hot summers. The annual precipitation in the region varies between 700–900 mm. The average annual temperature is 11–14°C, the average temperature of January is close to 0°C, and the average temperature of July is 23–24°C.

In terms of resort climatology, Telavi and its surroundings belong to the moderately humid resort subzone of the plain and low-mountain zone of Eastern Georgia, which is characterized by mild snowless winters and very warm moderately humid summers. According to the Fedorov-Chubukov complex classification of climate, sunny and moderately humid weather prevails here throughout the year.

The following main types of weather prevail by seasons:

In the winter period, cloudy weather prevails, with almost 45% recurrence. About half of them are characterized by low cloudiness. Frosty weather is not uncommon, with a recurrence of about 30–35%. There is about 5–10% recurrence of cloudy, rainy and sunny, moderately humid and wet weather.

Frosty weather is not uncommon in early spring, with maximum 10–15% reoccurrence. In March, the occurrence of cloudy weather increases to 40%, and the occurrence of sunny, moderately humid and wet weather increases. Sunny, dry weather is common, and its frequency of occurrence reaches 20% in late spring.

In summer, the frequency of very hot and dry weather increases to 30% in June, 40% in July and 50% in August. So, the weather is very hot and very dry, with more than 10% recurrence in August. The incidence of rainy weather is up to 10%.

Table 1 shows the average monthly and annual numbers of days with intense and abundant precipitations in the city of Telavi.

Table 1. Days with intense and abundant precipitations in the city of Telavi

Post, number of days with precipitations	Month												Number of days in a year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Intense	0.1	0.2	0.3	0.7	1.8	1.8	1.2	0.8	0.7	0.9	0.4	0.2	9
Abundant	0.04	0.04	0.1	0.3	0.5	0.9	0.6	0.4	0.3	0.4	0.1	0.1	4

Results of field scientific research conducted in 2020–2024 in the catchment area of the Telaviskhevi river basin

In order to assess the current ecological processes in the catchment area of the Telaviskhevi River, the field reconnaissance research was carried out in two phases: 1–10 June, 2020 (first phase) and 15–20 June, 2024 (second phase).

The field scientific studies were conducted in the Telaviskhevi River bed in several directions, in particular, using GPS, GIS maps and a complex digital distance meter, the locations of subsidence and collapse of soils in the river bed, their coordinates and absolute above-sea levels were determined. At these locations, the slope angles of the riverbed and the collapsed soil were measured, and at the next stage, the volumes of dumped mass were determined. Longitudinal soil and ground profiles were constructed based on the recorded material and the corresponding geometric dimensions were plotted on them.

During the field survey, the current condition of the 3 anti-mudflow barrages in the River Telaviskhevi bed was recorded, taking into account the failed assemblies. The condition of both head- and tailraces of the structures was also assessed.

In the course of the investigations, sections of the riverbed eroded and accumulated under the influence of floods, as well as traces of mudflows, were recorded as confirmed by the relevant photographic materials.

In the River Telaviskhevi catchment basin, 3 eroded banks with alluvial processes were assessed. In the course of field studies we observed solid fractions transported by the alluvial mass in the riverbed, as well as forest fragments stuck in the river bed, forming a natural barrier, which further intensifies alluvial processes.

We observed traces of mudflow passage in the riverbed, which gives an idea of the intensification of erosion and flooding processes in the Telaviskhevi catchment.

Fig. 2 shows a map with the results of the field survey, which is about the collapse of the mountain slope in the catchment basin of the Telaviskhevi River and the geographical location of 3 anti-mudflow barrages, with the corresponding coordinates and Fig. 3 shows a general view of the erosive gully of the Telaviskhevi River.

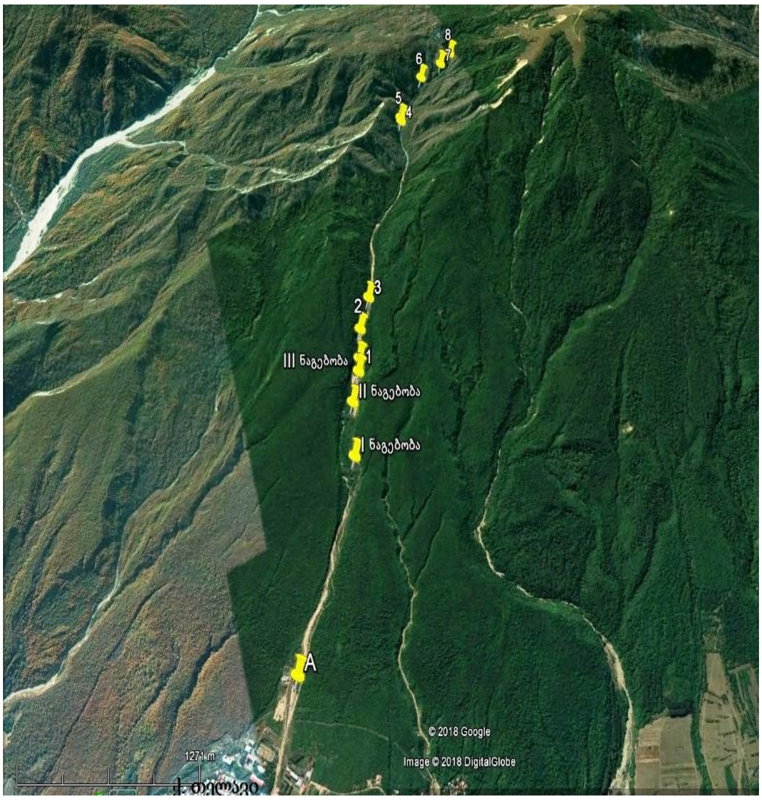


Fig. 2. Collapses of the soil and ground in the water catchment basin of the River Telaviskhevi

Fig. 3. General view of the erosive gully of the Telaviskhevi River

Mathematical modelling of floods and mudflows formed in the Telaviskhevi River bed

In addition to erosion processes, landslides on mountain slopes in the catchment area of the river or, in the case of mountain slopes, the crossing of the river channel and the destruction of the natural barrier created there by the volume of water mass accumulated in layers above play a major role in the occurrence of mudflows.

Based on the analysis of scientific research conducted in June 2018 in the sensitive areas of the right bank of the Telaviskhevi River, it can be concluded that in the case of surface landslides or mountain slopes, taking into account climatic factors and engineering and geological conditions, the Telaviskhevi River bed can be blocked with 10-meter-high ground mass, which in the case of a tectoseismogenic landslide is possible to increase to 15 m.

Fig. 4 shows different cases of eroded mass collapsed in Telaviskhevi bed in GPS coordinates.

Taking into account the field investigations and desk work, the main parameters of the subsidence soil were determined, the main quantitative data of which are shown in Table 2.

Table 2. Main parameters of the collapsed ground

No.	GPS-coordinates of the collapsed ground		Masl, H (m)	Length of the collapsed mass, L (m)	Mountain slope angle (degree)	Volume of the collapsed mass, W (m^3)
	X	Y				
1	0537453	4637753	1058	233,8	70^0	14909
2	0537382	4637535	1090	126,9	60^0	7394
3	0537228	4637304	1108	122,7	46^0	1652
4	0536370	4635756	1313	37,60	52^0	332
5	0536365	4635719	1322	55,4	60^0	907
6	0536001	4635363	1381	16,0	54^0	110
7	0535747	4635304	1418	30,0	45^0	789
8	0535613	4635249	1445	12,0	45^0	26

We have divided the raw data into two parts: the first is constant values and the second is variable values; The constant values include the parameters that do not depend on any conditions; As for the variable values, they depend on flooding, the degree of barrier collapse, etc [*Armanini etc., 2011; Gavardashvili etc., 2009; Gavardashvili, 2013, 2011, 2022; Mirtskhoulava, 1993*].

The volume of water (W0) accumulated in the upper basins created by the barrier was determined by the following relation [*Shoigu, 1998; Shterenlikht, 1984; Morgan etc., 2001*]:

$$W = \frac{H_B S_B}{3}, \text{ (mln m}^3\text{)} \quad (1)$$

where H_B is the water depth at the maximum flood level of the ground barrier (m); S_B is the area of so-called reservoir water surface formed by the ground barrier (mln m^3);

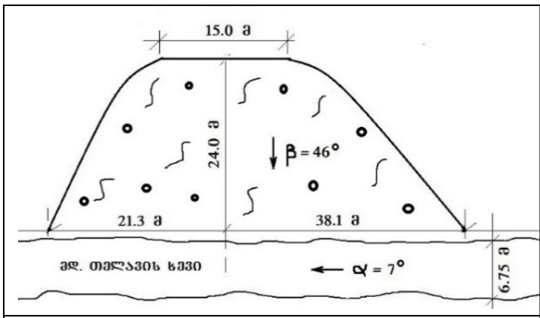
The width of the river is taken from digital topographic maps, and the number of points should not exceed 3 points on one side of the river axis, 6 points in total, and should include the whole catchment area in the design section.

The number of design cross-sections to determine the flooded area from the land boundary in the tailrace direction should not exceed 8 (Fig. 3), the distance between which should be marked in advance on the digital topographic map.

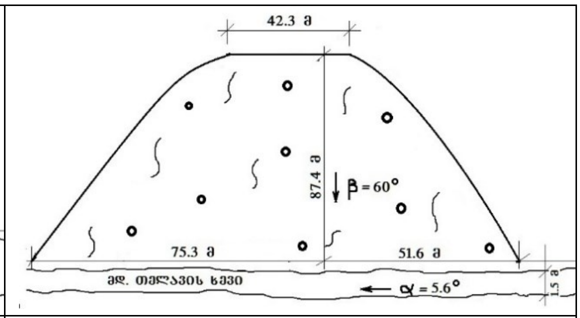
When a natural barrier collapses, the velocity of the flood (mudflow) wave (V) in the barrier tailrace shall be calculated using the following formula [*Natural hazards…, 2011; Natishvili etc., 2019, 2015; Chernomorets, 2005*]:

$$V = V_0 (H_1/H_0)^{2/3}, \text{ (m/s)} \quad (2)$$

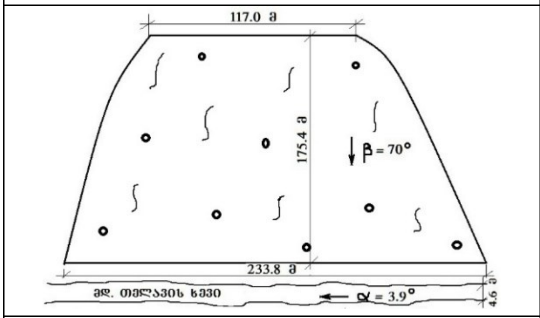
where V_0 is the velocity of water in the river in the tailrace of the structure (m/s); H_1 is the height of water in the river in the barrier tailrace (m); H_0 is the height of water in the river during the flood (m).



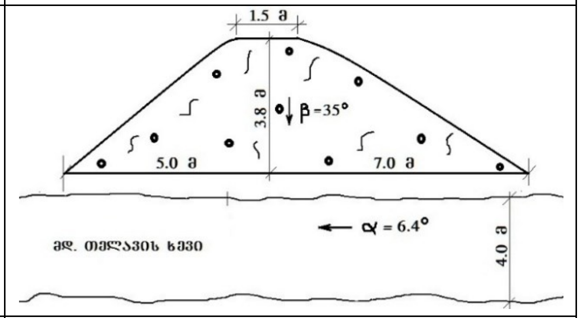
X – 0537453; Y- 4637753



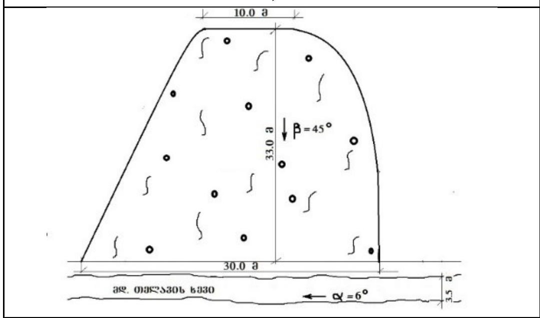
X – 0537382; Y- 4637535



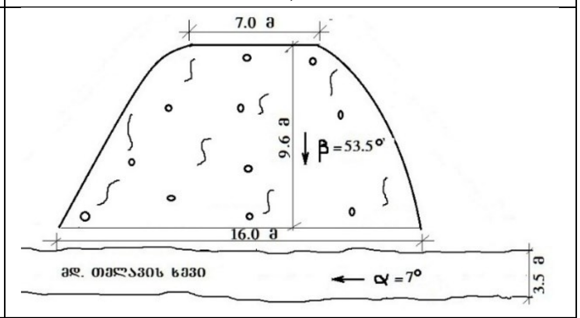
X – 0537228; Y- 4637304



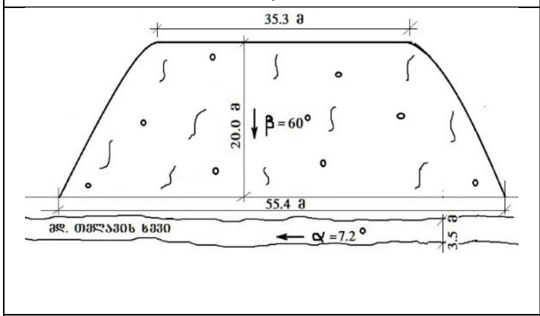
X – 0536370; Y- 4635756



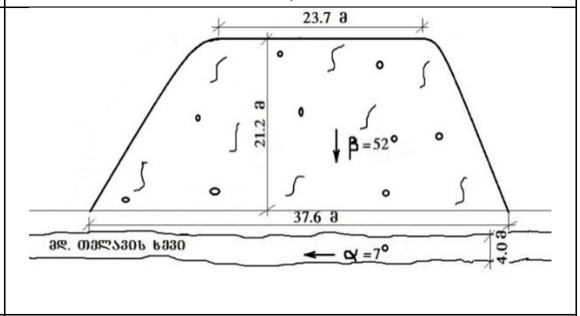
X – 0536365; Y- 4635719



X – 0536001; Y- 4635363



X – 0535747; Y- 4635304



X – 0535613; Y- 4635249

Fig. 4. Longitudinal profiles of collapsed inert mass

The degree of destruction of the ground barrier (E_P) is determined by the following relation:

$$E_p = \frac{F_B}{F_0}, \quad (3)$$

where F_B is the area of bank failure (m^2); F_0 is the surface area (m^2).

In addition to the above, the algorithm gives the following values: the height of the river bank edge (m), the number of crossings along the river, the distance between crossings (km), the width of the river bed (m), the current velocity in the riverbed (m/s), the riverbed levels(m), etc. [*Chernomorets, 2005; Lin etc., 2009*].

Fig. 3. Design sections recorded in the Telaviskhevi River bed

Using special computer software VOLNA-4 and algorithm written by us, we established the geometric dimensions of hydrological, hydraulic and flooded areas in case of destruction of 10-metre barrier in the Telaviskhevi riverbed, with their quantitative values included in Tables 3–5.

Table 3. Work report. Name: Breakage report of the 10-meter barrier in the Telaviskhevi riverbed

No.	Baseline data	Unit of measurement	Qty
1	Volume of flooded water in the barrier headrace	mln. m^3	0.026
2	Water depth near the barrier	m	10
3	Water surface area	mln. m^2	0.0106
4	Barrier width	m	50
5	River depth in the barrier tailrace	m	0.21
6	River width in the barrier tailrace	m	4.4
7	River velocity in the barrier tailrace	m/s	1
8	Water depth at the moment of the barrier failure	m	10
9	Degree of barrier failure	-	1
10	Maximum flood level	m	0
11	Height of the riverbed bank failure line	m	1350
12	Number of transverse profiles in the riverbed	pcs.	8

Table 4. Data of calculation

Description of cross sections	Unit of measurement	Section No.							
		1	2	3	4	5	6	7	8
Distance of *i*-th section from the barrier	km	2.83	3.07	3.49	5.4	6.36	6.66	6.98	7.54
Specific current									
Water level	m	1048	1023	984	811	728	703	674	629
Depth	m	0.15	0.12	0.15	0.1	0.1	0.1	0.1	0.1
Width	m	1.5	1.6	1.5	7.5	7.5	8.3	8.3	7.8
Current velocity	m/s	1.5	1.5	1.5	0.6	0.6	0.6	0.6	0.6
Left bank									
Height of the riverbed bank failure line	m	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Width of the former riverbed	m	0.75	0.8	0.75	3.85	3.85	4.15	4.15	3.9
№ 1 horizontal level	m	1050	1024	986	814	731	707	678	633
Distance from the river axis to horizontal #1	m	53.7	30	31.76	20	26	24.8	8.5	8.4
№ 2 horizontal level	m	1053	1028	988	814.5	731.5	706.5	677.5	633.5
Distance from the river axis to horizontal № 2	m	67.1	65.3	49.9	36.5	98	38	41	15
№ 3 horizontal level	m	1058	1029	991	815	732	706	677	634
Distance from the river axis to horizontal № 3	m	86.1	70.5	68.1	55.3	170	50.1	77	24.5
Right bank									
Height of the riverbed bank failure line	m	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Width of the former riverbed	m	0.75	0.8	0.75	3.85	3.85	4.15	4.15	3.9
№ 1 horizontal level	m	1050	1025	985	814	731	707	678	633
Distance from the river axis to horizontal № 1	m	6.2	18.6	23.2	54	19.3	31	13.8	24.2
№ 2 horizontal level	m	1054	1030	987	814.5	731.5	708	678.5	632.5
Distance from the river axis to horizontal № 2	m	14.3	40.8	38.4	85	86.7	62	28.6	34.6
№ 3 horizontal level	m	1058	1035	991	815	732	709	679	632
Distance from the river axis to horizontal № 3	m	25.8	61.6	63.2	139	154	94	43.5	45.2

Principal conclusions and recommendations

Based on the processing and analysis of field scientific and theoretical studies conducted on the Telaviskhevi River in 2020–2024, the following main conclusions and recommendations can be made.

1. On the basis of field reconnaissance studies in the catchment area of the Telaviskhevi River, 8 areas of subsidence and collapse of the ground in the riverbed on the right slope of the mountain, partially blocking the riverbed, are identified. Their coordinates were determined using GPS and marked on a digital map using GIS-technologies.
2. The longitudinal profile of 8 ground collapse sites was constructed, geometric dimensions of the subsidence sites were determined and their volumes were calculated, the value of which varies within W = 25,65–14909,00 m^3.
3. As a result of field studies in the Telaviskhevi river bed two locations with coordinates A (X – 0535561; Y – 4635118) and B (X – 0536242; Y – 4635611), where flooding caused by the river occurred, were recorded. According to our calculation, the volume of their

mudflow mass is between 262.53 – 5062,50 m^3, and the volume of water accumulated in the headrace is 13 000 m^3 in the first case and 26,000 m^3 in the second.

Table 5. Calculation data of hydraulic parameters

Barrier failure parameters	Unit of measurement	Section No.								
		0	1	2	3	4	5	6	7	8
Distance of the section to the barrier	km	0	2.83	3.07	3.49	5.4	6.36	6.66	6.98	7.54
Water peak discharge in the cross section	thous. m^3/s	1.06	0.05	0.05	0.05	0.02	0.01	0.01	0.01	0.01
Time of:										
Wave front start	s	0	13.81	16.54	21.53	43.72	53.04	55.93	59.04	64.43
Wave reduction	s	0	7.74	8.37	9.54	25.37	34.02	36.88	40	45.57
Wave tail reduction	s	0.53	31.98	34.64	39.31	92.37	119.0	127.4	136.3	151.8
Flooding	s	0.53	18.17	18.1	17.78	48.64	66	71.43	77.22	87.38
Peak current velocity	m/s	6.01	2.19	2.01	2.01	2.55	2.55	2.52	2.55	2.52
Wave height	m	5.79	0.92	0.79	0.82	0.78	0.73	0.69	0.68	0.66
Maximum flooding depth	m	6	1.07	0.91	0.97	0.88	0.83	0.79	0.78	0.76
Maximum flooding level	m	1346	1049	1024	984.8	811.8	728.7	703.7	6747	629.7
Maximum flooding width:										
On the left bank of the river	m	18.13	16.17	17.8	7.91	8.99	9.27	9.17	8.31	7.83
On the right bank of the river	m	18.13	2.82	4.83	15.29	12.81	8.66	9.5	8.58	8.54

4. By means of field and theoretical studies the erosion coefficient for three eroded slopes was determined (E = 0.031 – 0.114), the quantitative level of which corresponds to erosion class 3, i.e. the annual intensity of erosion is up to 5–10 tonnes per hectare considered to be quite high.

5. 8 sites of land subsidence and collapse of the mountain slope on the right slope in the Telaviskhevi River bed may pose a threat to the inhabitants of the city of Telavi, as the riverbed is narrowed by inert mass and the sites of collapse mentioned above work as runoff-guiding dams and in case of catastrophic floods or landslides it is quite possible that the runoff will rise on the left bank of the river and pose a threat to the local population, as well as to buildings of various purposes located on the left bank of the river.

6. The left bank of the Telaviskhevi River is very sensitive compared to the right bank and it is recommended to carry out appropriate engineering measures in some risky sections, as depending on the wandering type of the riverbed, even with normal water discharge, it is possible for the water flow to enter the carriageway and then onto the residential houses of Telavi residents.

7. In the 1980s 3 so-called flood control dams, so called "Shrekeulidze building" were built to regulate floods and mudflows formed in the Telaviskhevi River. During field investigations it was found that some parts of the building have failed and it is recommended to rehabilitate them immediately. Otherwise in case of a natural disaster the buildings may fail and the risk of impact of natural disasters to Telavi and its population may increase significantly.

8. The tailraces of all three structures are gullied under the impact of from water flows, and in some places the process has reached down the foundation of the structure. Also the energy dumping reinforced concrete blocks are overturned and are out of order. It is recommended that the head- and tailraces be rehabilitated immediately to allow the buildings to function properly.

9. In case of destruction of the channel configuration of the Telaviskhevi River and the 10-meter-high natural barrier in its bed, the main hydrological and hydraulic parameters

of the flood wave (mudflow) movement in 8 sections of the river are determined by using the computer software 'Volna-2', taking into account the time factor, as well as flooded areas in the Telaviskhevi riverbed, left and right from the river axis.

10. By means of mathematical calculations it has been established that floods and mudflows, which can occur in the riverbed in case of 10 m barrier destruction as a result of collapse of the landslide mass or mountain slope, the concrete-lined bed of the Telaviskhevi River passes this natural disaster with the calculated parameters provided the spaces at the bridge crossings are not filled with dry bushes and woody material in the riverbed transported by the mudflow.

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