5 Hydrology

As available run-off records are from the period of 1928-1940 and 1953-1990 and since no records exist since 1990, potential climate change influence on run-off in the Tergi river was studied. Based on international studies on climate change (reference (3)), the effects in Georgia are considered very small. As a general trend the summers will be drier and winters will be wetter which is positive for hydropower.

The remaining part of this chapter 5 is unchanged from the feasibility study.

5.1 Catchment area

Starting on the northern slopes of Mount Zilgakokh (3856 m) at 3400 m above sea level on the Caucasus Ridge, the Tergi River joins the Caspian Sea north of Agrakhan Peninsular in the territory of Russian Federation.

The length of the river from the head to the section of the headworks of the design HPP is 58.2 km, total fall – 2537 m, average slope – 43.5%. The area of the catchment basin is 59.6 km. The length of the river to the power-unit room of the design HPP is 59.6 km, total fall – 2598 m, and average slope – 43.6%. The area of the catchment basin is 980 km.

From the head to the section of the headworks of the design HPP, the river is joined by 34 first order tributaries with the combined length of 210 km. The most important of the tributaries are the Snostskali, the Baidara, the Mnaisi, the Suatisi, the Gimara, the Desikami, the Amali and the Kistura. The Mnaisi, the Suatisi and the Desikami are mud torrent-prone rivers. It is generally known that on 17 August 1953 and on 6 August 1967 the mud torrents flowing through the above rivers and other tributaries to the Tergi blocked and consequently overflowed the riverbed, causing serious material damage to Kazbegi Region. The Amali River is particularly worth-mentioning, as the ice lobe over its right tributary (starts flowing from Devdoraki Glacier) broke off and displaced towards the Tergi River. According to the theoretical estimates available, the ice lobe breaking off and sliding down the Amala Gorge at high speed can block the Tergi riverbed and cause impoundment and stagnation. If the impoundment-causing ice lobe suddenly breaks through and the stagnant water escapes, disastrous consequences will be unavoidable.

The geological structure of the Tergi River basin is formed with Early, Medium and Late Jurassic shale, sandstone, limestone and marl. The latest (quaternary) effusions, lime tuff sediments brought by springs, travertines, ice and river extensions. It is noteworthy that the young volcanoes here are located on erosive, mountainous, dissected surface.

Alpine and sub-Alpine meadows are prevalent in the basin. There is almost no forest here. Foliage shrubs find occurrence in certain areas, basically in the lower parts of the tributary gorges.

The soil cover of the basin is mainly formed with mountain-meadow lawn and mountain-forest-meadow soils, a certain part of which has been washed down.

Glaciers find a frequent occurrence in the basin, playing an important part in feeding the rivers. Susaiti, Mna, Ortsveri and Devdoriki are relatively large glaciers.

The river gorge from the head down to Resi Village has a V-like form. Downstream to Okrokana Village, the river widens, assuming a box-like form. In this section, where the gorge bottom is 1-1.3 km in width, the Tergi River branches, forming a few islands. The gorge at Okrokana Village narrows for about 2 km in length and after that widens again.

The riverbed is mildly tortuous, branching in widened sections. In the design HPP diversion area, the river flows into one deeply cut bed. The flow depth from the heads downstream varies from 0.6 to 1.5 m, the flow width – from 13 to 20 m and the flow speed – from 1.7 to 2.4 m/s. The riverbed bottom is uneven, rocky, and blocked with massive lumps of rock.

The river feeds on glacier, snow, rain and ground waters. Its water regime is characterized with spring-summer flooding and unstable shoals in other seasons of the year. The spring-summer flooding induced by melting snow and glaciers and seasonal rains normally sets in April, reaching its peak in July and abating in September. Minimum water levels are observed in February.

The Tergi River in the territory of Georgia is currently not used for business purposes.

5.2 Climate

The Tergi River basin down to the design section is located on the northern slope of the Caucasus Ridge opening down to the Russian plain, due to which the north cold air currents get here without hindrance. Therefore, winter is severe and summer is relatively cool here.

One of the main factors accounting for the climate conditions prevalent in the region is air temperature, the average monthly and annual values of which, according to the results of perennial observations of the weather stations in the river basin down to the design section, are presented in Table 5.1 below.

Table 5.1: Average monthly and annual air temperatures t^0C

W. Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Kazbegi h/m*	-15,0	-15,3	-12,2	-8,0	-3,5	-0,3	3,0	3,4	0,0	-4,1	-8,6	-12,3	-6,1
Kazbegi	-5,2	-4,7	-1,5	4,0	9,0	11,8	14,4	14,4	10,6	6,6	1,5	-2,6	4,9
Kobi	-8,0	-6,6	-2,9	2,7	8,1	11,6	13,8	13,9	9,8	5,2	-0,5	-5,4	3,5
Jvari Pass	-11,4	-10,8	-7,2	-1,6	3,8	7,8	10,5	10,6	6,8	2,1	-4,6	-8,7	-0,2

*h/m = high mountainous

The absolute maximum air temperature of 32^0 in the region is observed in Kazbegi. Table 5.2 below gives absolute maximum air temperatures according to the results of years of observations of the same weather stations.

Table 5.2: Absolute maximum air temperatures t^0C

W. Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Kazbegi h/m	1	3	5	9	10	11	16	16	14	12	8	4	16
Kazbegi	13	14	20	23	26	29	32	32	30	27	22	18	32
Kobi	10	12	16	20	24	26	27	28	27	24	19	16	28
Jvari Pass	7	10	14	15	19	23	27	27	27	19	15	8	27

The absolute minimum air temperature of -42^0 in the region is observed by Kazbegi high mountainous weather station. Table 5.3 below gives absolute minimum air temperatures according to the results of years of observations of the same weather stations.

Table 5.3: Absolute minimum air temperatures t^0C

W. Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Kazbegi h/m	-42	-40	-34	-30	-19	-11	-10	-10	-18	-23	-31	-37	-42
Kazbegi	-34	-32	-25	-19	-10	-2	0	-1	-8	-16	-20	-28	-34
Kobi	-34	-31	-26	-18	-12	-2	0	-2	-10	-19	-23	-30	-34
Jvari Pass	-38	-33	-30	-24	-13	-5	-4	-4	-12	-20	-25	-32	-38

As the tables above show that the region's hottest month is August and coldest month is January.

The annual volume of precipitation in the region depends on the hypsometric development of the Tergi River basin. Therefore, the greatest volume of precipitation is observed by the weather stations located at high altitudes. It should also be mentioned that the annual progress of precipitation is characterized with maximum volume in the warm period (IV-X) of the year and minimum volume in the cold period (XI-III) of the year.

The average monthly volume and total annual volume of precipitation according to the results of perennial observations of the same weather stations are presented in Table 5.4 below.

Table 5.4: Average monthly volume and total annual volume of precipitation in mm

W. Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Kazbegi h/m	63	71	95	147	183	165	150	169	121	99	83	58	1404
Kazbegi	22	28	43	73	105	99	87	85	68	51	33	24	718
Kobi	39	54	78	101	139	135	122	98	91	77	59	47	1040
Jvari Pass	81	104	119	147	198	177	143	122	110	108	102	92	1503

The volume of atmospheric precipitation occurring on one day in the region is quite high. According to Kobi Weather Station perennial observations, the volume of precipitation falling on a single day of 21 October 1899 amounted to 115 mm. Different supply volumes of maximum daily precipitation according to the perennial observations of Kazbegi and Kobi Weather Stations are presented in Table 5.5.

Table 5.5: Different supply volumes of maximum daily precipitation

Weather station	Average maximum	Supply %						Observed maximum	
		63	20	10	5	2	1	mm	Date
Kazbegi	48	41	59	70	82	100	114	111	1.IX.1965
Kobi	57	46	72	86	98	112	120	115	21.X.1899

The average annual value of water vapour tension (absolute humidity or vapour density) is not high. It drops as the altitude grows. The annual progress of absolute humidity and vapour deficit virtually coincides with the annual progress of air temperature.

The region gets winds blowing in all directions but southerly winds prevail over relatively lower levels of the Tergi River gorge (Kazbegi and Kobi Weather Stations) while Kazbegi High Mountainous Weather Station gets westerly and Jvari Pass – north-easterly winds as prevailing winds.

The annual recurrence of wind direction and number of calms according to the perennial observations of the same weather stations are presented in Table 5.6.

Table 5.6: Annual recurrence of wind direction and number of calms in %

W. Station	N	NE	E	SE	S	SW	W	NW	Calm
Kazbegi h/m	2	1	2	1	2	6	76	10	38
Kazbegi	25	2	1	4	57	9	1	1	30
Kobi	11	9	2	10	41	25	2	0	39
Jvari Pass	7	31	1	6	23	23	8	1	38

The average maximum wind speed is observed by Kazbegi High Mountainous Weather Station. The average annual wind speed observed by the weather stations on Jvari Pass and in the gorge does not exceed 20 m/s. Besides, the average monthly maximum wind speeds are observed in winter months and minimum wind speeds in summer months.

The average monthly and annual wind speeds according to the perennial observations of the same weather stations are presented in Table 5.7.

Table 5.7: Average monthly and annual wind speeds in m/s

W. Station	Weathercock height	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Kazbegi h/m	11 m	7,0	7,5	7,4	7,0	6,1	4,8	5,0	5,4	6,4	7,1	6,6	6,8	6,4
Kazbegi	9 m	2,6	2,6	2,4	2,0	1,6	1,5	1,4	1,6	1,7	2,0	2,2	2,5	2,0
Kobi	10 m	1,7	1,9	1,9	1,3	1,4	1,3	1,5	1,4	1,6	1,5	1,9	1,7	1,6
Jvari Pass	11 m	2,2	2,4	2,2	1,8	1,9	2,0	1,9	2,0	2,0	2,0	1,9	2,2	2,0

Maximum wind speeds of varying recurrence are presented in Table 5.8 below.

Table 5.8: Maximum wind speeds of varying recurrence

W. Station	Maximum wind speed (m/s) occurring only once				
	In 1 year	In 5 years	In 10 years	In 15 years	In 20 years
Kazbegi h/m	49	57	60	63	65
Kazbegi	14	17	19	20	21
Kobi	21	25	26	27	28

5.3 Hydrological records

A method of analogy has been used to calculate the design values of the average annual flow rates of the Tergi River at the design section of headworks. Perennial observations of Kazbegi (Stepantsminda) Hydrological Watch Point have been taken as an analogy. The observations cover the periods from 1928 to 1940 and from 1953 to 1990. The observations for the missing period from 1940 to 1953 cannot be restored, as the observations conducted by North Caucasus Weather Station are very difficult to obtain now. Therefore, the explanatory report for hydrological evidence does not present average monthly values of flow rates for all the years observed.

Nevertheless, according to the information that we obtained in the past few years for the period from 1928 to 1975 regarding average annual flow rates, a 51-year variation series (1928-1940, 1953-1990) has been obtained, based on which the average annual flow rates of the Tergi River in the section of Kazbegi Hydrological Watch Point range from 18.6 m^3/s (1934) to 38.6 m^3/s (1987).

A statistical processing of the 51-year variation series by a method of moments yields the following parameters of the distribution curve:

Average perennial value of average annual flow rates $Q_0 = \frac{\Sigma Q_i}{n} = 24{,}7$ m^3/s;

Variation coefficient $C_v = \sqrt{\frac{\Sigma(K-1)^2}{n-1}} = 0{,}14$;

Coefficient of asymmetry $C_s = 2 \cdot C_v = 0{,}28$.

The parameters to assess the representativeness of the variation series have been identified:

- The relative average square error of the average perennial value of average annual flow rates that amounts to $\varepsilon_{Q_0} = \frac{C_v}{\sqrt{n}} \cdot 100 = 1{,}96$ %;
- The relative average square error of the variation coefficient $\varepsilon_{C_v} = \sqrt{\frac{1+C_v^2}{2 \cdot n}} \cdot 100 = 10{,}0$ %.

The parameters so obtained are satisfactory, as according to Construction Standards and Rules, $\varepsilon_{Q_0} \leq 5\%$ and $\varepsilon_{C_v} \leq 15\%$.

The above parameters of the distribution curve and three-parameter distribution ordinates have been used to determine various supply values of the average annual flow rates of the Tergi River in the section of Kazbegi Hydrological Watch Point (HWP).

Conversion from the analogy (Kazbegi HWP) to the section of the design hydropower diversion headworks is made by means of a conversion coefficient (factor), the value of which is obtained by using the following formula:

$$K = \left(\frac{F_{des}}{F_{anal}}\right)^N$$

Where F_{des} - the Tergi River catchment basin area in the design section, F_{des} = 806 km^2; and F_{anal} - the Tergi River catchment basin area in the analogy, i.e. Kazbegi HWP section, F_{anal} = 778 km^2;

N - reduction power, the value of which in the event of average annual flow rates would be equal to 0,8.

Entering the above numerical values in the above expression helps us obtain the value of the analogy to design section conversion coefficient (factor) equalling 1.029. Multiplying the average annual flow rates fixed in Kazbegi HWP section by the conversion factor generates the average annual flow rates of the Tergi River in the design HPP diversion headworks section.

The average annual Tergi River flow rates of different supplies in Kazbegi HWP and design sections are presented in Table 5.9 below.

Table 5.9: Average annual flow rates with different supplies of the Tergi River, m^3/s

Section	F km^2	Q_0 m^3/s	C_V	C_S	K	Supply P %						
						10	25	50	75	80	90	95
Kazbegi HWP	778	24,7	0,14	0,28	_	32,5	28,4	24,2	20,4	19,7	17,5	15,9
Design Section	806	25,4	_	_	1,029	33,4	29,2	24,9	21,0	20,3	18,0	16,4

A within-year distribution of the design supply (10%, 50% and 90%) average annual flow rates by months in the design HEP diversion headworks section has been performed in synchronicity with the average perennial values of the average monthly flow rates in Kazbegi HWP section. The findings are presented in Table 5.10. The table also gives the sanitary flow value of the river (accounting for 10% of the average perennial flow rate of the river in the water intake section) as well as the volume of water to be taken by the HEP on the condition the sanitary flow is left in the river.

Table 5.10: Within-year distribution of the design supply average annual flow rates of the Tergi River in the design HEP diversion headworks section

F=806 km^2, Q_0=25,4 m^3/s. $Q_{san.}$=2,54 m^3/s.

Flow rate	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
10 % flow rate (surplus water)													
Average monthly into the headworks	11,7	11,0	11,1	19,0	48,1	76,1	78,6	56,5	34,6	23,7	16,8	13,6	33,4
Sanitary flow	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54
To HEP	**9,16**	**8,46**	**8,58**	**16,5**	**45,5**	**73,6**	**76,3**	**54,0**	**32,1**	**21,2**	**14,3**	**11,1**	**30,9**
50 % flow rate (medium water flow)													
Average monthly in the headworks	8,74	8,20	8,36	14,2	35,8	56,7	58,6	42,2	25,8	17,7	12,4	10,1	24,9
Sanitary flow	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54
To HEP	**6,20**	**5,66**	**5,82**	**11,7**	**33,3**	**54,2**	**56,3**	**39,7**	**23,3**	**15,2**	**9,86**	**7,56**	**22,4**
90 % flow rate (shallow water)													
Average monthly in the headworks	6,37	5,92	6,00	10,3	25,9	40,9	42,4	30,4	18,7	12,8	9,00	7,31	18,0
Sanitary flow	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54	2,54
To HEP	**3,83**	**3,38**	**3,46**	**7,80**	**23,4**	**38,6**	**39,9**	**27,9**	**16,2**	**10,3**	**6,46**	**4,77**	**15,5**

As was mentioned above, the observations from 1928 to 1976 was conducted by North Caucasus Weather Station and records on the river Tergi run-off published in north Caucasus hydrological data. The information on within-year distribution of the design average annual flow rates per days is impossible to obtain now. Therefore, distribution of the design average annual flow rates, only within year pursuant to 10 days, are possible and are given in Table 5.11.

Table 5.11: Within-year distribution of the design supply average annual flow rates of the Tergi river in the design HPP headwork section pursuant to 10 days

10-days	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
10 %- flow rate(surplus water)													
I	11,7	11,0	11,0	12,1	34,2	68,2	94,8	60,0	41,0	24,6	17,3	13,6	-
II	11,7	11,0	11,0	14,8	52,7	74,5	77,5	57,4	34,3	23,5	17,1	13,6	-
III	11,7	11,0	11,3	30,1	56,6	85,6	64,9	52,5	28,5	23,1	16,0	13,6	-
Ave. monthly	11,7	11,0	11,1	19,0	48,1	76,1	78,6	56,5	34,6	23,7	16,8	13,6	33,4
50 %- flow rate(medium water)													
I	8,74	8,20	8,24	9,04	25,4	50,8	70,7	44,8	30,6	18,4	12,8	10,1	-
II	8,74	8,20	8,28	11,0	39,2	55,5	57,8	42,9	25,6	17,6	12,6	10,1	-
III	8,74	8,20	8,55	22,5	42,1	63,7	48,4	39,2	21,2	17,2	11,8	10,1	-
	8,74	8,20	8,36	14,2	35,8	56,7	58,6	42,2	25,8	17,7	12,4	10,1	24,9
90 %- flow rate(shallow water)													
I	6,37	5,92	5,91	6,58	18,4	36,6	51,2	32,4	22,2	13,4	9,30	7,31	-
II	6,37	5,92	5,94	8,02	28,4	40,1	41,8	30,9	18,6	12,7	9,14	7,31	-
III	6,37	5,92	6,14	16,3	30,5	46,0	35,0	28,2	15,4	12,4	8,56	7,31	-
Ave. monthly	6,37	5,92	6,00	10,3	25,9	40,9	42,4	30,4	18,7	12,8	9,00	7,31	18,0

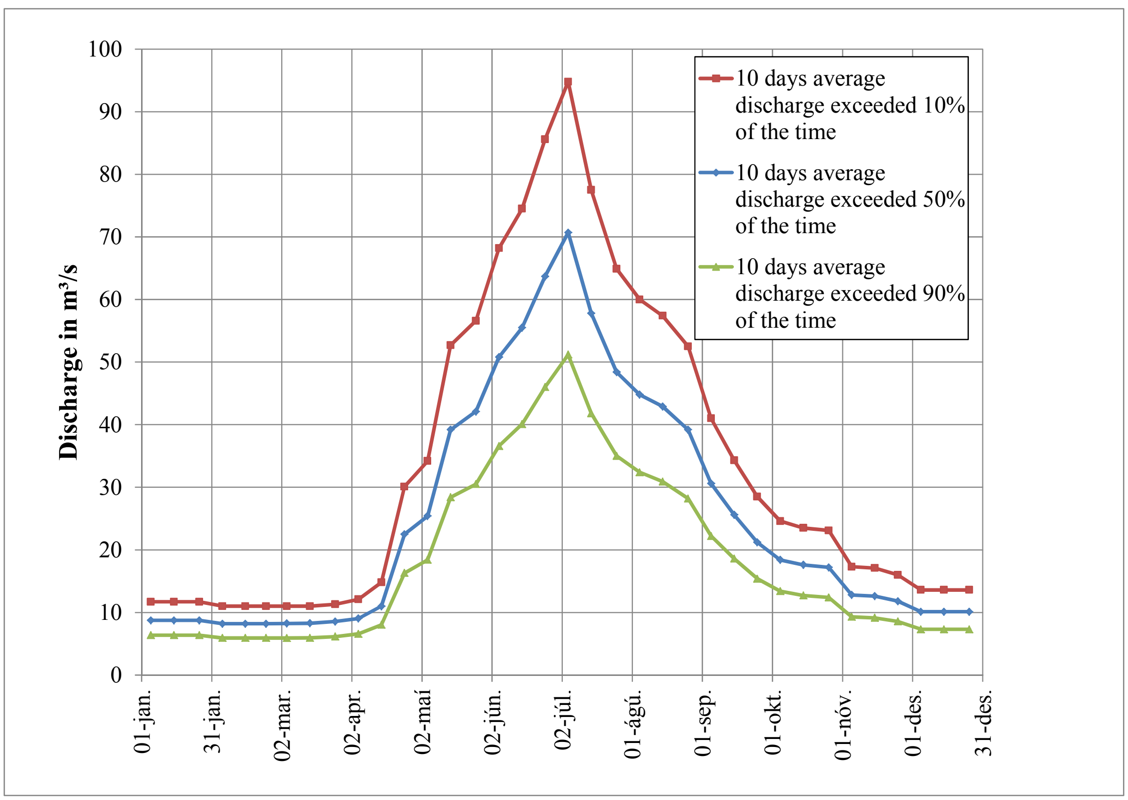

Figure 5.1: 10 days average discharges at Dariali intake.

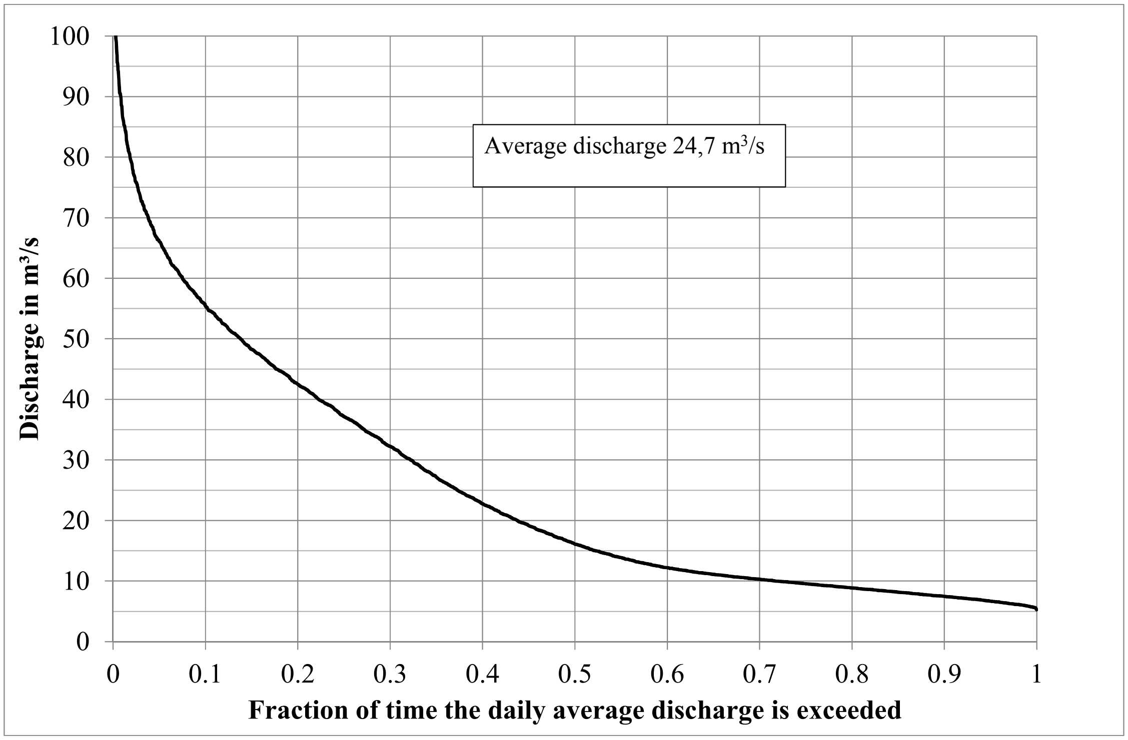

Figure 5.2: Duration curve of discharge to Dariali HPP

5.4 Maximum discharges

A method of analogy has been used to calculate the design values of the maximum annual flow rates of the Tergi River at the design section. Perennial observations of Kazbegi (Stepantsminda) Hydrological Watch Point have been taken as an analogy. The observations cover the periods from 1928 to 1940 and from 1953 to 1990. A statistical processing of the 51-year variation series by a method of moments yields the following parameters of the distribution curve:

- Average perennial value of maximum annual flow rates $Q_0 = \frac{\Sigma Q_i}{n} = 130$ m^3/s;
- Variation coefficient $C_v = \sqrt{\frac{\Sigma(K-1)^2}{n-1}} = 0{,}55$;
- Coefficient of asymmetry $C_s = 4 \cdot C_v = 2{,}20$.

The parameters to assess the representativeness of the variation series have been identified:

- The relative average square error of the average perennial value of maximum annual flow rates that amounts to $\varepsilon_{Q_0} = \frac{C_v}{\sqrt{n}} \cdot 100 = 7{,}70$ %;
- The relative average square error of the variation coefficient $\varepsilon_{C_v} = \sqrt{\frac{1+C_v{}^2}{2 \cdot n}} \cdot 100 = 11{,}3$ %.

The parameters so obtained are satisfactory, as according to Construction Standards and Rules, $\varepsilon_{Q_0} \leq 10\%$ and $\varepsilon_{C_v} \leq 15\%$.

The average square deviation has also been calculated as equal to $\delta = 71{,}5$.

The above parameters of the distribution curve and three-parameter distribution ordinates have been used to determine various supply values of the maximum flow rates of the Tergi River in the section of Kazbegi HWP.

As the variation value exceeds 0.50, the distribution curve parameters have been calculated by a graphic-analytical method as well, at which time the coefficient of asymmetry is determined as S function of the flatness factor. Its value is calculated by the following formula:

$$S = \frac{Q_{5\%} + Q_{95\%} - 2 \cdot Q_{50\%}}{Q_{5\%} - Q_{95\%}}$$

The average perennial value of maximum flow rates is calculated by the following formula:

$$Q_0{}^I = Q_{50\%} - \Phi_{50\%} \cdot \delta$$

The average square error is calculated by the following formula:

$$\delta = C_v \cdot Q_0{}^I = \frac{Q_{5\%} - Q_{95\%}}{\Phi_{5\%} - \Phi_{95\%}}$$

where $Q_{5\%}$, $Q_{50\%}$ and $Q_{95\%}$ are 5, 50 and 95% supply values of maximum water flow rates respectively, calculated from the empirical curve of supply;

$\Phi_{5\%}$, $\Phi_{50\%}$ and $\Phi_{95\%}$ are 5, 50 and 95% rated ordinates of binomial curve of supply.

The calculations performed by a graphic-analytical method have identified the following distribution curve parameters:

- Average perennial value of maximum annual flow rates $Q_0{}^I = 137$ m^3/s;
- Variation coefficient $C_v = 0{,}59$;
- Coefficient of asymmetry $C_s = 2{,}30$;
- Average square error $\delta = 80{,}7$.

The parameters obtained by a graphic-analytical method and the rated ordinates of the binomial curve of distribution have been used to determine different supply values of the Tergi River maximum flow rates in Kazbegi HWP section.

Conversion from the analogy (Kazbegi HWP) to the section of the design HPP diversion headworks is made by means of a conversion coefficient (factor), the value of which is obtained by using the same formula that was applied in connection with the average annual flow rates but the reduction power in connection with the maximum flow rates equals 0.5. Therefore, the conversion factor in the event of maximum flow rates would equal 1.018. Multiplying the maximum flow rates calculated in Kazbegi HWP section by the conversion factor brings us to the maximum flow rates of the Tergi River in the design HPP diversion headworks section.

The different supply values of the maximum flow rates of the Tergi River obtained by both of the above methods in Kazbegi HWP and the design HPP diversion headworks sections are presented in Table 5.12 below.

Table 5.12: Different supply values of the maximum flow rates of the Tergi River, m^3/s

Section	km^2	Method	QQ_0 m^3/s	Cv	Cs	δ	Supply P%						
							0.1	0.5	1	2	3	5	10
Kazbegi HWP	778	moments	130	0,55	2,20	71,5	595	445	385	345	300	260	215
		graphic-analysis	137	0,59	2,30	80,7	645	505	440	380	345	300	240
Design K =1,018	806	moments	132	-	-	-	605	455	390	350	305	265	220
		graphic-analysis	140	-	-	-	**660**	**515**	**450**	**390**	**350**	**305**	**245**

The flow rates calculated by a graphic-analytical method have been accepted as the estimated values of the maximum flow rates of the Tergi River in the design section.

In the diversion section, the Tergi River has eight right-bank tributaries, which are planned to be crossed by means of a diversion pipeline (canal), on account of which their maximum water flow rates have also been determined. These tributaries have not been studied from a hydrological standpoint. Therefore, their maximum estimated flow rates have been calculated by the method recommended for calculation of maximum flow rates of the rivers having a catchment basin of up to 300 km^2 under the Technical Guideline for Calculation of Maximum River Runoff in Caucasus and USSR Surface Water Resources (a hydrological handbook), Volume IX, Edition I.

By the above method, maximum water flow rates are calculated by the formula:

$$Q = 16,67 \cdot \alpha \cdot \beta \cdot \delta \cdot F \cdot \frac{H}{T} \text{ m}^3/\text{s}$$

where T is the estimated time (in minutes) of maximum water runoff in the design section. Its value is calculated by the formula:

$$T = \left[\frac{L_{day}}{\varphi \cdot \sqrt{i^m{}_a \cdot \alpha \cdot l_0 \cdot K \cdot \tau^{0,27}}} \right]^{1,53} \text{ minutes}$$

where L_{day} is the “reduced” length of the river in metres. Its value is calculated by the formula:

$$L_{day} = \frac{L}{S} + l_0 \text{ metres}$$

Here L is length of flow in metres from the river head to the design section.

S _ correlation of the speeds of the rivers flowing in the riverbed and down the gorge slopes.

l_0 _ estimated length of slope in meters. Its value is calculated by the formula:

$$l_0 = \frac{1000 \cdot F}{2 \cdot (L + \Sigma l)} \text{ metres}$$

Where F _ river catchment basin area in km^2;

Σl _ combined length of tributaries in km.

φ _ density of plant cover in the basin. Its value is obtained from a specially developed table, which in this particular case equals 0,34;

$i^m{}_a$ _ catchment basin slope in %, and $m = 0{,}6$;

α _ maximum runoff coefficient. Its value is calculated by the formula:

$$\alpha = \xi \cdot (i + 0{,}1)^{0{,}345} \cdot T^{0{,}15}$$

Here ξ _ coefficient of the soil cover in the basin. Its value is obtained from a specially developed map and the relevant table.

i _ intensity of rainfall in the basin in mm/min; $i = \frac{H}{T}$;

Here H _ estimated volume of rainfall in the basin in mm. Its value is calculated by the formula:

$$H = K \cdot \tau^{0{,}27} \cdot T^{0{,}31} \text{ mm when } T \geq 20 \text{ minutes and}$$

$$H = 0{,}637 \cdot K \cdot \tau^{0{,}27} \cdot T^{0{,}46} \text{ mm when } T \leq 20 \text{ minutes}$$

Where K _ climate coefficient of the region.

τ _ recurrence in years;

β _ unequal distribution of rainfall in the basin. Its value is calculated by the formula:

$$\beta = e^{-0,2 \cdot F^{0,6} \cdot \sqrt[3]{i} \cdot T^{-0,25}}$$

Here e _ basis for natural logarithms;

δ _ basin form coefficient. Its value is calculated by the formula:

$$\delta = 0,25 \cdot \frac{B_{\max}}{B_{aver}} + 0,75$$

Where $B_{\max}$ - average basin width in km;

B_{aver} - average basin width in km. Its value is calculated by the formula $B_{aver} = \frac{F}{L}$;

The values of the morphometric elements needed for calculation of the maximum flow rates of the right tributaries to the Tergi River in the design section, based on the 1:25000 topographic map, are presented in Table 5.13 below.

Table 5.13: Morphometric elements of the right tributaries to the Tergi River

Section	F km²	L km	i kal	i_a %	Σl km	ξ	φ	K	δ
Gorge №1	7,95	5,10	0,384	62,0	4,80	0,27	0,34	7	1
Gorge №2	1,51	2,80	0,489	66,0	1,00	0,27	0,34	7	1
Gorge №3	1,09	3,15	0,613	65,5	1,20	0,27	0,34	7	1
Gorge No4	0,21	1,30	0,454	50,7	0,20	0,27	0,34	7	1
Gorge №5	2,02	2.90	0,584	66,0	1,50	0,27	0,34	7	1
Gorge №6	1,73	2,65	0,472	80,0	1,50	0,27	0,34	7	1
Gorge №7	2,02	2,60	0,500	67,5	1,30	0,27	0,34	7	1
Gorge №8	2,50	2,40	0,500	75,0	1,40	0,27	0,34	7	1

All the necessary parameters fixed for calculation of maximum water flow rates based on the given morphometric elements and the values of maximum water flows are presented in Table 5.14 below.

Table 5.14: Maximum water flows of the right tributaries to the Tergi River, m^3/s

Section	τ year	$P\%$	T min	H mm	i mm/min	α	β	v m/s kal.	v m/s slop.	Q m^3/s
Gorge №1	100	1	60,0	86,4	1,44	0,58	0,755	2,13	0,36	83,5
	50	2	64,9	73,5	1,13	0,54	0,775	2,01	0,31	63,0
	20	5	73,1	59,6	0,82	0,50	0,801	1,87	0,25	43,5
	10	10	78,5	50,4	0,64	0,47	0,818	1,76	0,21	32,5
Gorge №2	100	1	37,7	74,8	1,98	0,60	0,878	1,76	0,31	26,5
	50	2	40,6	63,5	1,56	0,56	0,889	1,66	0,26	19,5
	20	5	45,3	51,4	1,14	0,52	0,902	1,54	0,22	13,5
	10	10	50,8	44,0	0,87	0,48	0,912	1,44	0,18	9,55
Gorge №3	100	1	38,3	75,2	1,96	0,60	0,900	1,78	0,24	19,5
	50	2	41,2	63,8	1,55	0,56	0,908	1,68	0,21	14,5
	20	5	45,6	51,5	1,13	0,52	0,919	1,56	0,17	9,80
	10	10	50,3	43,9	0,87	0,48	0,927	1,46	0,14	7,05
Gorge №4	100	1	23,2	64,4	2,78	0,62	0,951	1,28	0,20	5,75
	50	2	24,6	54,4	2,21	0,58	0,955	1,21	0,17	4,30
	20	5	27,9	44,2	1,58	0,53	0,961	1,13	0,14	3,10
	10	10	30,3	37,5	1,24	0,50	0,965	1,05	0,12	2,10
Gorge №5	100	1	35,5	73,4	2,07	0,60	0,853	1,97	0,34	35,5
	50	2	39,8	63,1	1,59	0,56	0,868	1,85	0,29	26,0
	20	5	45,4	51,4	1,13	0,51	0,885	1,71	0,23	17,5
	10	10	50,0	43,8	0,88	0,48	0,896	1,61	0,20	13,0
Gorge №6	100	1	34,7	72,9	2,10	0,60	0,864	1,81	0,34	31,5
	50	2	37,6	62,1	1,65	0,56	0,876	1,71	0,29	23,5
	20	5	42,3	50,3	1,19	0,52	0,891	1,58	0,24	16,0
	10	10	47,1	43,0	0,91	0,48	0,902	1,48	0,20	11,5
Gorge №7	100	1	35,3	73,3	2,08	0,60	0,852	1,89	0,36	36,0
	50	2	38,5	62,5	1,62	0,56	0,866	1,78	0,31	26,5
	20	5	43,6	50,7	1,16	0,52	0,883	1,64	0,25	18,0
	10	10	48,9	43,5	0,89	0,48	0,895	1,54	0,21	13,0
Gorge №8	100	1	33,6	72,2	2,15	0,61	0,830	1,98	0,43	45,5
	50	2	36,4	61,4	1,69	0,57	0,845	1,87	0,37	34,0
	20	5	42,1	50,2	1,19	0,52	0,866	1,72	0,30	22,5
	10	10	47,7	43,1	0,90	0,48	0,880	1,60	0,25	16,0

It is worth mentioning that most of the right tributaries to the Tergi River are prone to mud torrents. As the tributaries leave mud torrent masses in the floodplains of the Tergi River where the diversion pipeline (canal) is to be built and where alluvium and sediments get accumulated due to reduction of the bed slopes, such masses cannot present any danger to the diversion canal built in the section. Therefore, it was not thought advisable to determine the maximum mud flow rates of such tributaries.

To identify the levels of the maximum flow rates of the Tergi River in the design area, cross sections of the beds were made based on which the hydraulic elements of the rivers were determined. The hydraulic elements were used to build maximum flow rate and level Q=f(H) relationship curves, which are tied to each other by choosing a hydraulic gradient of the flow between two design sections.

The average flow rate in the section is calculated by the formula that is used to determine the average flow rate of mountain rivers in stone-gravel beds. The formula looks as follows:

$$v = 11.6 \cdot t^{0.5+\frac{0.74}{2.3+0.35 \cdot t^2}} \cdot i^{0.36+2 \cdot i}$$

Where t – average flow depth in the section, m;

i _ hydraulic gradient of the flow between two design sections.

Table 5.15 below gives the water levels relevant to the maximum flow rates of the Tergi River.

Table 5.15: Maximum water levels of the Tergi River

Traverse N	Distance between Traverses	Water bank level, m abs	Lowest bottom level, m abs	Maximum water level				
				$\tau=200$ years, Q=515 m^3/s	$\tau=100$ years, Q=450 m^3/s	$\tau=50$ years, Q=390 m^3/s	$\tau=20$ years, Q=305 m^3/s	$\tau=10$ years, Q=245 m^3/s
1		1728,80	1728,03	1731,20	1731,00	1730,80	1730,50	1730,30
	30 m							
2 Design section		1726,35	1725,35	1729,20	1729,00	1728,70	1728,40	1728,10
	90 m							
3		1722,55	1721,50	1725,40	1725,20	1725,00	1724,60	1724,40
	90 m							
4		1719,25	1718,33	1721,90	1721,70	1721,40	1721,10	1720,80
	135 m							
5		1710,88	1710,35	1712,60	1712,40	1712,20	1712,00	1711,80
	75 m							
6		1705,28	1704,53	1707,50	1707,30	1707,10	1706,80	1706,60
	90 m							
7		1697,75	1696,95	1700,00	1699,90	1699,70	1699,40	1699,20

Table 5.16: Hydraulic elements of the Tergi River near headworks

Levels m a.s.l.	Section elements	Section area ωM m^2	Flow width B m	Average depth h m	Flow gradient i	Average speed Mv m/s	Water discharge Q m^3/s
Traverse #5 L =75 m.							
1710,88	Riverbed	15,8	44,7	0,35	0,075	1,74	27,5
1711,50	Riverbed	44,2	47,0	0,94	0,071	3,28	145
1712,00	Riverbed	68,1	48,6	1,40	0,070	4,25	289
1712,50	Riverbed	92,9	50,6	1,84	0,068	5,03	467
1713,00	Riverbed	119	52,5	2,27	0,067	5,75	684
Traverse #4 L = 135 m							
1719,25	Riverbed	11,9	19,3	0,62	0,062	2,32	27,6
1720,00	Riverbed	28,3	24,4	1,16	0,064	3,58	101
1720,50	Riverbed	41,4	28,0	1,48	0,066	4,28	177
1721,00	Riverbed	56,2	31,0	1,81	0,067	4,94	278
1721,50	Riverbed	72,7	35,0	2,08	0,068	5,46	397
1722,00	Riverbed	91,2	39,2	2,33	0,069	5,94	542
Traverse #3 L =90 m.							
1722,55	Riverbed	14,1	20,0	0,70	0,037	1,94	27,4
1723,00	Riverbed	24,1	24,5	0,98	0,037	2,43	58,6
1723,50	Riverbed	37,7	30,0	1,26	0,037	2,88	109
1724,00	Riverbed	54,0	35,0	1,54	0,038	3,34	180
1724,50	Riverbed	73,0	41,0	1,78	0,039	3,73	272
1725,00	Riverbed	94,8	46,0	2,06	0,039	4,11	390
1725,50	Riverbed	119	50,0	2,38	0,039	4,53	539
Traverse #2 L =90 m Headworks dam site							
1726,35	Riverbed	13,5	20,2	0,67	0,042	2,01	27,1
1727,00	Riverbed	28,7	26,5	1,08	0,042	2,77	79,5
1727,50	Riverbed	43,3	32,0	1,35	0,042	3,21	139
1728,00	Riverbed	60,8	38,0	1,60	0,042	3,60	219
1728,50	Riverbed	81,3	44,0	1,85	0,042	3,97	323
1729,00	Riverbed	105	49,0	2,14	0,042	4,37	459
1729,50	Riverbed	131	56,0	2,34	0,042	4,64	608
Traverse #1 L =30 m.							
1728,80	Riverbed	11,6	22,6	0,51	0,082	2,34	27,1
1729,50	Riverbed	29,3	28,0	1,05	0,074	3,60	105
1730,00	Riverbed	44,8	34,0	1,32	0,072	4,14	185
1730,50	Riverbed	63,2	39,5	1,60	0,072	4,71	298
1731,00	Riverbed	84,3	45,0	1,87	0,070	5,16	435
1731,50	Riverbed	108	50,0	2,16	0,067	5,56	600

5.5 Minimum discharges

A method of analogy has been used to calculate the design values of the minimum annual flow rates of the Tergi River at the design section. Perennial observations of Kazbegi (Stepantsminda) Hydrological Watch Point have been taken as an analogy. The observations cover the periods from 1928 to 1940 and from 1953 to 1990. A statistical processing of the 51-year variation series by a method of moments yields the following parameters of the distribution curve:

Average perennial value of minimum annual flow rates $Q_0 = \frac{\Sigma Q_i}{n} = 7{,}13$ m^3/s;

Variation coefficient $C_v = \sqrt{\frac{\Sigma(K-1)^2}{n-1}} = 0{,}21$;

Coefficient of asymmetry $C_s = 2 \cdot C_v = 0{,}42$.

The parameters to assess the representativeness of the variation series have been identified:

The relative average square error of the average perennial value of minimum annual flow rates that amounts to $\varepsilon_{Q_0} = \frac{C_v}{\sqrt{n}} \cdot 100 = 2{,}9\%$;

The relative average square error of the variation coefficient $\varepsilon_{C_v} = \sqrt{\frac{1 + C_v^2}{2 \cdot n}} \cdot 100 = 10{,}1\ \%$.

The parameters so obtained are satisfactory, as according to Construction Standards and Rules, $\varepsilon_{Q_0} \leq 10\%$ and $\varepsilon_{C_v} \leq 15\%$.

The above parameters of the distribution curve obtained by a method of moments and three-parameter distribution ordinates have been used to determine various supply values of the minimum flow rates of the Tergi River in the section of the analogy, i.e. Kazbegi HWP.

Conversion from the analogy (Kazbegi HWP) to the section of the design HPP diversion headworks is made by means of a conversion coefficient (factor) applicable in the event of average annual flow rates. The results are presented in Table 5.17 below.

Table 5.17: Minimum flow rates of the Tergi River of different supplies, m^3/s

Section	F km^2	QQ_0 m^3/s	Cv	Cs	δ	Supply P%					
						75	80	90	95	97	99
Kazbegi HWP	778	7.13	0.21	0.42	1,50	6.07	5.86	5.30	4.87	4.61	4.12
Design K =1,029	806	7,34	-	-	-	6,24	6,03	5,45	5,01	4,74	4,24

5.6 Ice conditions

It is noteworthy that when the air temperature drops below -6.8 °C from November through March in some years, bottom ice will develop in the river. Therefore, frazil ice flushing may be necessary during extreme cold spells in the winter time.

5.7 Sediment regime

Perennial observations of Kazbegi (Stepantsminda) Hydrological Watch Point covering the period from 1928 to 1940 have been used to calculate the design values of the solid discharge of the Tergi River at the design section.

A statistical processing of the 12-year variation series of average annual solid discharge by a method of moments yields the following parameters of the distribution curve:

Average perennial value of solid discharge $R = \frac{\Sigma R_i}{n} = 24{,}1$ kg/s

Variation coefficient $C_v = \sqrt{\frac{\Sigma(K-1)^2}{n-1}} = 0{,}93$;

Coefficient of asymmetry $C_s = 4 \cdot C_v = 3{,}72$ has been determined by matching the empirical points of solid discharge with the theoretical curve on the probability cellule.

The above parameters of the distribution curve and three-parameter distribution ordinates have been used to determine various supply values of the solid discharge of the Tergi River in the section of Kazbegi HWP.

The methods of determining the bed load discharge have been developed with poor precision. The main reason for it is the imperfection of the devices available and the complexity of the load movement study. Therefore, the volume of bed load for mountain rivers by theoretical calculations is assumed to be 50% of solid discharge.

Table 5.18 below sets forth the solid discharge, bed load and respective values in the event of different supplies of the Tergi River at Kazbegi HWP section.

Table 5.18: The Tergi River – Kazbegi HWP different solid discharge supply values

Supply P%	1	3	5	10	20	50	75	90
Solid discharge R kg/s	110	78	64	48	34	22	10	7
Solid discharge runoff W thousand tons	3470	2460	2020	1520	1075	695	315	220
Bed load runoff R_I kg/s	55	39	32	24	17	11	5	3
Bed load runoff W_I thousand tons	1735	1230	1000	755	535	345	155	95
$\Sigma R + R_I$ kg/s	165	117	96	72	51	33	15	10
$\Sigma W + W_I$ thousand tons	5200	3690	3020	2275	1610	1040	470	315

No data is available as regards the turbidity of the Tergi River at Kazbegi HWP section. Therefore, the average perennial turbidity of the river is calculated by the following formula:

$$\rho = \frac{1000 \cdot R_0}{Q_0} \text{ g/m}^3$$

Where ρ _ average perennial water turbidity value in g/m^3;

- R_0 _ average perennial solid discharge of the Tergi River at Kazbegi HWP section. Its value that has been calculated by using the 12-year observation data, equals 24,1 kg/s.
- Q_0 _ average perennial value of the average annual discharges of the Tergi River that equals 24,7 m^3/s.

Entering the given numerical values to the above expression yields the average perennial turbidity value of the Tergi River – 975 g/m^3.

The Tergi and Kistura riverbed processes have not been studied in the design area. Therefore, maximum bed washout depth for the rivers is determined by the method recommended in the Technical Guideline for Calculation of the Stable Bed in Designing Waterworks in the Alluvial Beds of Mountain Rivers.

According to the above method, the general average expected bed washout depth in the straight-line section of the river is calculated by the following formula:

$$H_S = \frac{K}{i^{0,03}} \cdot \left(\frac{Q_{p\%}}{\sqrt{g}} \right)^{0,4}$$

Where K is the coefficient taking into account the heterogeneity of water flow and suspended solid particles. Its value depends on the quantity of suspended solid particles (μ g/l) and a correlation of the average flow depth and the average diameter of the bed covering load ($\frac{H}{d_{\text{cov}}}$) is taken from a special table.

The quantity of suspended particles is calculated by the following formula:

$$\mu = 7000 \cdot \left(\frac{H}{d_{dep}} \right)^{0,7} \cdot i^{2,2} \text{ g/l}$$

Where H is the average flow depth in the design section. Its value that is taken from the hydraulic elements of the Tergi River Traverse N14 (headworks section) equals 2,45 m, and for the Kistura River (according to Traverse N3) – 1,50 m;

d_{dep} _ average diameter of the solid material deposited on the riverbed. Its value is determined by the following formula:

$$d_{dep} = K \cdot i^{0,9} \cdot \left(\frac{Q_{10\%}}{\sqrt{g}} \right)^{0,4} \text{ m}$$

Here K _ the coefficient taking into account the heterogeneity of water flow and suspended solid particles in it. Its value that depends on the quantity of suspended solid particles (μ g/l), and is taken from the relevant table, equalling 1,6 for both rivers;

i _ the hydraulic gradient of flow in both formulas in the design section that equals 0,049 for the Tergi River and 0,068 for the Kistura River;

$Q_{10\%}$ _ maximum discharge of 10% supply that accounts for 280 m^3/s for the Tergi River (headworks section) and 115 m^3/s – for the Kistura River;

g _ acceleration of gravity force in both formulas.

Entering the given numerical figures to the above formulas yields μ =23,0 g/l and d_{dep} = 0,64 m for the Tergi River. Out of this $d_{\text{cov}} = d_{dep} \cdot 1,8 = 1,15$ m, and the correlation $\frac{H}{d_{\text{cov}}} = \frac{2,45}{1,15} = 2,15 \leq 3$ and to which K =0,43 from the relevant table will be related;

The same values for the Kistura River have the following results:

μ =35,9 g/l, d_{dep} = 0,60 m. Out of this $d_{\text{cov}} = d_{dep} \cdot 1,8 =$ 1,08 m, and the correlation $\frac{H}{d_{\text{cov}}} = \frac{1,50}{1,08} = 1,39 \leq 3$ and to which K =0,43 from the relevant table will be related;

$Q_{p\%}$ – maximum water discharge for the estimated supply. In this particular case, the maximum discharge of a 1% supply of the Tergi River in the headworks section amounts to 510 m^3/s and the same value for the Kistura River – 250 m^3/s.

Entering the given numerical figures to the above formula yields 3,61 m as the average Tergi River bed washout depth and 2,71 m as the average Kistura River bed washout depth.

The maximum depth of the general bed washout is calculated by the following formula:

$$H_{\max} = 1{,}6 \cdot H_s$$

According to the above expression, the maximum depth of the general washout of the Tergi riverbed in the headworks section accounts for 5,80 m and that of the Kistura – 4,35 m.

The above maximum depths of the general washout of the beds must be re-measured downstream the 100-year recurrence maximum water discharge levels of the rivers.