Blue Rivers®
Environmental Consulting

BAKHVI 2 HYDROPOWER PROJECT, GEORGIA

Climate change risk management

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Introduction

The Blue Rivers® Environmental Consulting (further "Consultant") has signed a contract with Schulze Global Georgia Partnership Limited regarding climate change risk management for hydropower projects in Georgia.

Hydropower has generally been viewed as a sustainable, clean, low-carbon source of energy, but climate variability is putting its future under threat. Hydropower is particularly vulnerable to the effects of climate change – and the impact of the changes in rainfall and water availability, protracted drought events, significant variation in temperature regimes, and more frequent and severe weather events.

With this regard, the Consultant should assess possible climate changes in the hydropower project area, and evaluate these changes in terms of how they will affect electricity generation by Bakhvi 2 (2A and 2B) HPP in the future.

1. Baseline description of the Project area

1.1 Overview of the Project area

Based on Memorandum signed with the Government of Georgia, CCEH Hydro VII LLC plans to implement a project on HPP construction and operation on the territory of Chokhatauri and Ozurgeti municipalities, in Guria region.

According to the Feasibility Study, the project activities consider utilization of hydropower potential of Bakhvistskali river from the section between elevations over 2,700 m asl to 1,378 m asl at the Bakhvi 2A intake and 1,057 m asl at the Bakhvi 2B intake.

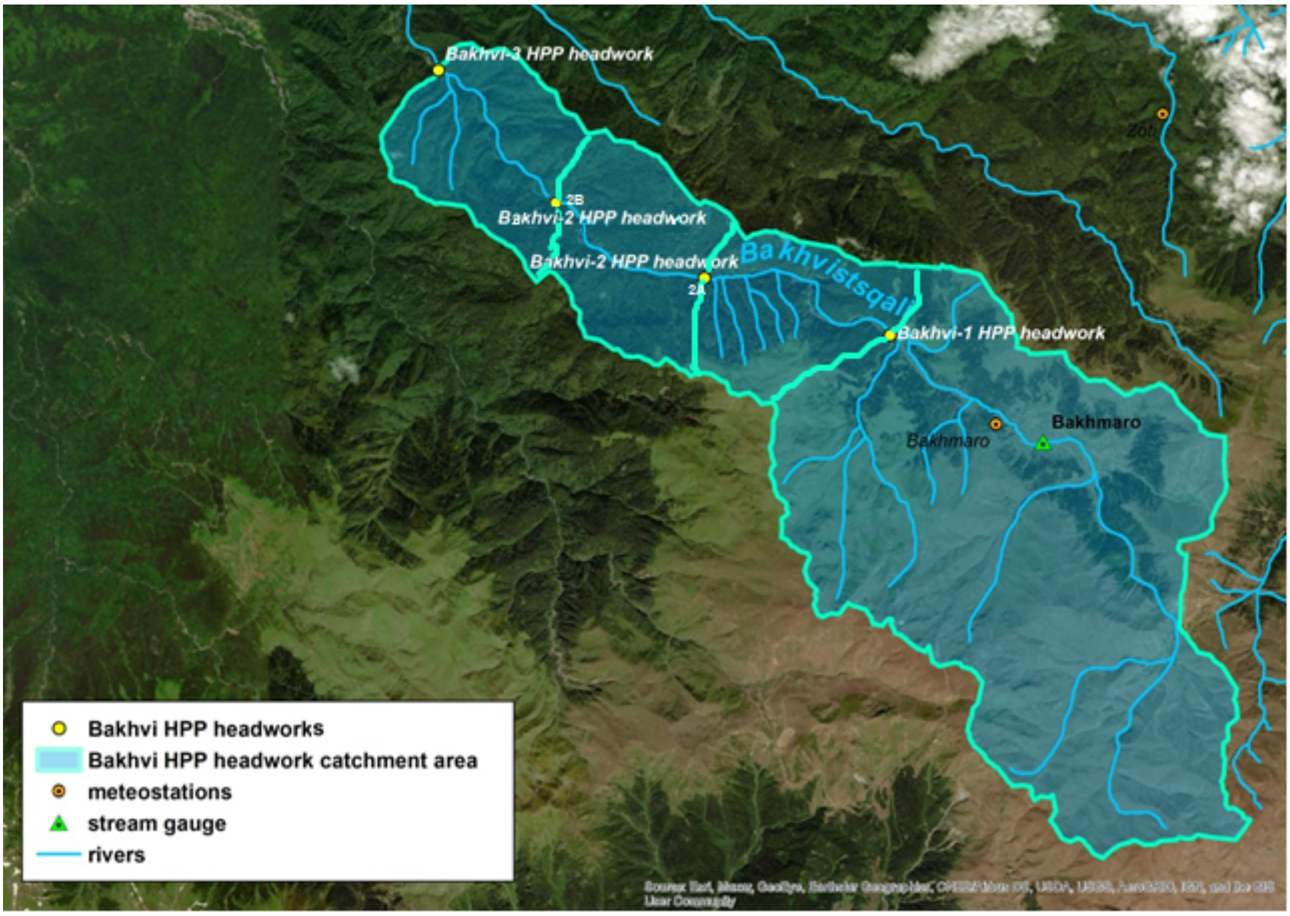

Figure 1. Bakhvi 2 HPP location

Bakhvistskali River

Bakhvistskali river is the main hydrological artery of the region. The total length of the river is 42 km, the catchment area is 156 km^2, River feeding is mixed, with dominance of snow melt and underground water. The multiannual water discharge in the mouth is 6.2 m^3/s. It is characterized with high water in spring and low water – in summer and autumn. Bakhvistskali river mainly flows within V-shaped valley, in some places it creates very narrow canyon-like forms. It is characterized with steep inclination of slopes.

1.2 Climate and Meteorological Conditions

Bakhvistskali river basin is located in the subtropical humid climate region.

Data on air temperature and precipitation in the basin according to the meteorological stations are presented in Tables 1 and 2.

Table 1. Air temperature data from Bakhmaro and Ozurgeti meteorological stations

MS*	Monthly average air temperature, °C												Annual average	Absolute min	Absolute max.
	1	2	3	4	5	6	7	8	9	10	11	12			
Bakh	-5.8	-4.6	-2.3	2.5	7.3	10.4	13.4	13.5	9.6	4.8	-1	-1.4	2.5	-38	30
Ozurgeti	4.8	5.4	8	12	16.6	20	22.3	22.6	19.4	15.4	10.4	6.9	13.6	-19	41

MS - meteorological stations

Table 2. Precipitation data from Bakhmaro, Ozurgeti, Kveda Bakhvi and Vakijvari meteorological stations

MS	Monthly average precipitation, mm												11-3	4-10	Year
	1	2	3	4	5	6	7	8	9	10	11	12			
Bakh maro	209	203	174	87	96	126	107	114	153	214	201	185	972	897	1869
Ozur geti	198	186	139	110	81	130	156	179	224	235	223	212	958	1115	2073
Kveda Bakhvi	198	166	133	76	64	115	125	156	212	243	200	193	890	991	1881
Vakijvari	226	192	154	87	74	128	142	176	238	276	226	221	1019	1121	2140

2. Research results

The approach of assessment is based on recommendations of the International Hydropower Association "Climate Change Resilience Guide for Hydropower" issued in 2019. The specific objective of this approach is to ensure climate resilience of the portfolio investments, i.e. to put them in a capacity to absorb the stresses imposed by climate change and to evolve into greater robustness.

According to the methodology, provided by the client, four tasks must be performed within the research.

The obtained assessment results for tasks are presented below.

Task 1: Average hydrological regime shift

The average hydrological regime shift is determined by changes in the seasonal distribution, intensity and form (snow or rain) of precipitations.

Objective: to identify the most likely climate change scenarios and its implications on the average annual volume of precipitations at the catchment area level, and to translate it in hydrological trends.

The method for Task 1 is the following one:

- Access to regional climate change projections on the World Bank Group’s Climate Change Knowledge Portal (CCKP)[1].
  - **Selected territory** – Bakhvi 2 HPP (Guria region),
  - **Variable** – monthly precipitation,
  - **Period** – 2040-2059,
  - **Projection** – latest IPCC ensemble,
  - **Scenario** – RCP 6.0.

The assessment of potential changes in the average hydrological regime of the Bakhvistskali River for the period 2040-2059 is based on applying to hydrological data the same change ratio provided for long-term average monthly precipitation values by the projection of RCP 6.0 scenario in 2040-2059 according to the CCKP.

The assessment was completed based on long-term series of meteorological observations of precipitation at the nearest meteorological station in the Bakhmaro resort. Monitoring of precipitation at Bakhmaro station was conducted during 1936-2010. Uninterrupted observations: **1936-1992, 1999-2006, 2010 years.**

Taking into account conditions of the work with the web-site CCKP, historical data for the Bahmaro meteostation were compared with projected data for the whole Guria.

At the web-site CCKP, the forecast of precipitations is done based on the reference period 1986-2005 years (Figure 2).

[1] https://climateknowledgeportal.worldbank.org/country/georgia/climate-data-projections

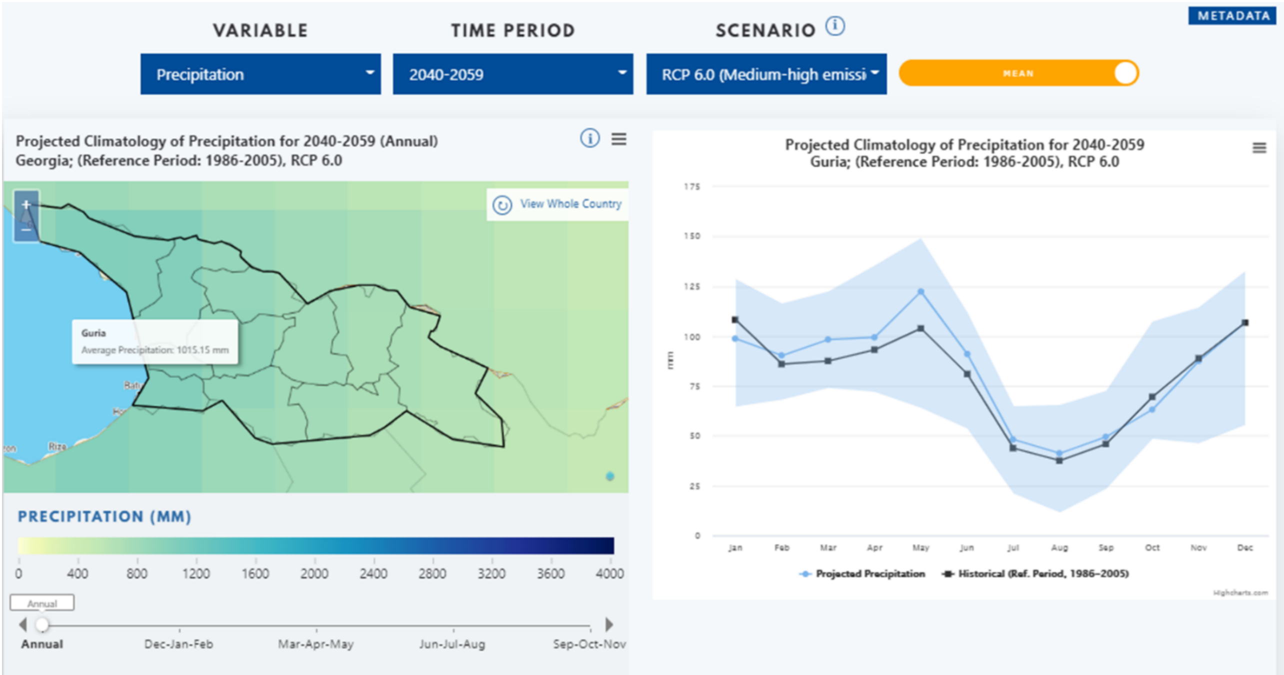

Figure 2. Climate Change Knowledge Portal (CCKP), precipitation data

Monthly precipitation delta for Guria region between the reference period 1986-2005 and the projected period 2040-2059 presented in Table 3.

Table 3. Monthly precipitation delta for Guria region

Month / Parameter	Precipitation (mm)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Guria historical (1986-2005)	108.24	86.03	87.58	93.24	103.89	81.04	43.86	37.59	45.98	69.61	88.93	106.78	**952.77**
Guria projected (2040-2059)	98.78	90.37	98.36	99.43	122.37	91.05	48.19	41.28	49.58	63.20	87.57	106.83	**997.01**
delta_1 (%)	-8.74	5.04	12.31	6.64	17.79	12.35	9.87	9.82	7.83	-9.21	-1.53	0.05	**4.64**

According to the results of the ratio of the observed values of precipitation with the values obtained from the projection of climate change in the scenario of RCP 6.0 climate change for the period 2040-2059 the annual precipitation is expected to increase by 4.6%, compared with the average value of the period 1986-2005.

During the period of long-term observations, the average annual precipitation in the Guria region was 953 mm. In the period 2040-2059 precipitation is expected with an average value of 997 mm per year. Increase of the amount of precipitations is typical for almost each month of the year, except October, November and January. The biggest growth of the monthly amount of precipitation is expected in May (17.8%) (Figure 3).

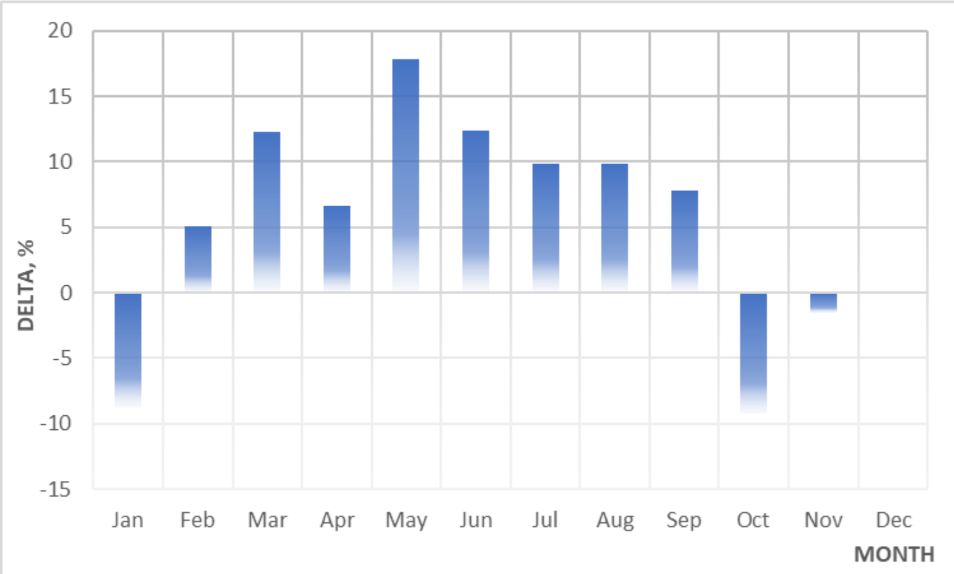

Figure 3. Delta (%) of the monthly amount of precipitation in the period 2040-2059 compared to the values of the period 1986-2005

Taking into account that there is a correlation between the amount of the precipitation and discharge, one can get the data on future discharge for the period 2040-2059 using delta for Guria region mentioned in the Table 3. This is of course a first-order approximation, which is in line with the IHA simplified approach for small and medium size hydropower schemes.

Forecast of the discharge for the period 2040-2059 is done in several stages:

I. *To calculate the discharge in the reference period 1986-2005. For this a few tasks were done:*

1. Water discharge observation period at hydrological station Bakhmaro is defined, which corresponds to the period of precipitation monitoring and covers 49 years: from 1937 to 1986
2. Delta between precipitation for the periods 1937-1986 and 1986-2005 is defined (Table 4).

Table 4. Delta between precipitation for reference period 1986-2005 and for period 1937-1986

Bakhmaro meteorological stations	Precipitation, mm												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1937-1986, mm	153	142	118	76	94	121	91	104	140	193	159	166	**1558**

Bakhmaro meteorological stations	Precipitation, mm												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1986-2005, mm	170	112	100	87	104	133	79	108	137	166	190	160	**1547**
delta_2 (%)	-10.2	26.9	17.9	-12.3	-9.4	-8.9	16.0	-3.6	1.9	16.3	-16.5	3.4	**0.7**

3. Delta_2 from Table 4 was added to the average monthly water flow layers[2] for the period 1937-1986. In this way, the water flow layer (mm) for the reference period 1986-2005 was defined (Table 5).

Table 5. Monthly and annual water flow layers for reference period 1986-2005

r.Bakhvi, hydrological gauge Bahmaro resort	Water flow layer (mm)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1937-1986	51	41	53	209	476	344	177	113	92	103	90	150	**1813**
1986-2005 = 1937-1986 + delta_2	45	51	62	183	431	313	206	109	93	119	75	155	**1825**

II. Delta_1 from Table 3 was added to the average monthly water flow layers for the reference period 1986-2005. In this way, the water flow layer (mm) for the forecasted period 2040-2059 was defined (Table 6).

Table 6. Projected monthly and annual water flow layer for period 2040-2059

r.Bakhvi, hydrological gauge Bahmaro resort	Water flow layer (mm)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
2040-2059 = 1986-2005 + delta_1	41	54	70	195	508	352	226	120	101	108	74	155	**1910**

III. Average monthly values of water discharge for the period 1937-1986 and forecasted for the period 2040-2059 in m^3/s are presented in the Table 7.

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[2] Water flow layer is the ratio of water volume over a certain period of time from the catchment area.

Table 7. Monthly and annual flow in m³/s

r.Bakhvi, hydrological gauge Bakhmaro resort	Water discharge (m³/s)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1937-1986	0.63	0.56	0.66	2.69	5.94	4.43	2.21	1.41	1.18	1.28	1.16	1.87	**1.92**
2040-2059	0.52	0.75	0.87	2.51	6.34	4.53	2.82	1.49	1.30	1.35	0.95	1.94	**2.02**

Average monthly water discharges of 50% probability for Bakhvistskali river at the points Bakhvi 2A and Bakhvi 2B HPP headworks are taken from the document «HPP Bakhvi 2 – Feasibility Study. Volume 6 – Hydrology, Draft Report –R00» (AFRY Austria GmbH, 2021) (Table 8, 9).

Table 8. Monthly and annual flow with 50% provision

Flow (m³/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bakhvi 2A HPP headwork	0.9	0.8	1.1	4.0	9.6	7.3	2.9	1.9	1.6	1.7	1.8	1.4
Bakhvi 2B HPP headwork	1.0	0.9	1.2	4.6	11.0	8.4	3.4	2.1	1.9	2.0	2.0	1.6

The value of the water discharges of 50% probability for the prognosed period 2040-2059 can be calculated using delta between average monthly values of water discharge of the two periods: 1937-1986 and 2040-2059 (Table 9).

Table 9. Monthly and annual flow values with 50% provision in 2040-2059

Flow (m3/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1937-1986	0.63	0.56	0.66	2.69	5.94	4.43	2.21	1.41	1.18	1.28	1.16	1.87	**2.00**
2040-2059	0.52	0.75	0.87	2.51	6.34	4.53	2.82	1.49	1.30	1.35	0.95	1.94	**2.11**

Flow (m3/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
delta_3	0.83	1.34	1.32	0.93	1.07	1.02	1.28	1.06	1.10	1.05	0.82	1.04	**1.07**
delta_3, %	-17.5	33.9	31.8	-6.7	6.7	2.3	27.6	5.7	10.2	5.5	-18.1	3.7	**7.10**
Bakhvi 2A HPP headwork 50% flow (according Report)	0.9	0.8	1.1	4.0	9.6	7.3	2.9	1.9	1.6	1.7	1.8	1.4	**2.92**
Bakhvi 2A HPP headwork 50% flow (for 2040-2059)	0.74	1.07	1.45	3.73	10.24	7.47	3.7	2	1.76	1.79	1.47	1.45	**3.07**
Bakhvi 2B HPP headwork 50% flow (according Report)	1.0	0.9	1.2	4.6	11.0	8.4	3.4	2.1	1.9	2.0	2.0	1.6	**3.34**
Bakhvi 2B HPP headwork 50% flow (for 2040-2059)	0.83	1.21	1.58	4.29	11.74	8.59	4.34	2.22	2.09	2.11	1.64	1.66	**3.53**

According to the results, the average annual water availability with 50% provision in 2040-2059 in the Bakhvi 2A HPP headwork will increased by 0.15 m^3/s, in the Bakhvi 2B HPP headwork will increased by 0.19 m^3/s.

Forecasted distribution of the energy production was conducted based on the received values of discharge for the period 2040-2059 (Table 10).

Table 10. Monthly generation distribution for period 2040-2059

Flow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bakhvi 2A HPP												
Flow (m^3/s)	0.74	1.07	1.45	3.73	10.24	7.47	3.7	2	1.76	1.79	1.47	1.45
Generated Energy, GWh	1.18	1.47	2.08	5.33	8.36	7.69	6.76	3.57	3.09	3.29	2.26	2.33
Bakhvi 2B HPP												
Flow (m^3/s)	0.83	1.21	1.58	4.29	11.74	8.59	4.34	2.22	2.09	2.11	1.64	1.66
Generated Energy, GWh	2.42	2.97	4.15	10.90	17.18	15.78	13.79	7.27	6.28	6.68	4.60	4.73

In total annual generation based on the actual monthly river flows has been calculated by the company for upper section – 45.53 GWh, for lower section – 92.81 GWh. Annual energy generation calculated by us for the period 2040-2059 for upper section – 47.41 GWh (increased by 4.1%), for lower section – 96.75 GWh (increased by 4.2%).

Task 2: Increased hydrological variability

The average hydrological regime shift is determined by changes in the interannual distribution, intensity and form (snow or rain) of precipitations. **Objective:** to identify the most likely climate change in terms of interannual flow variability.

The **method for Task 2** is the following one:

- Access to regional climate change projections on the CCKP .
    - **Selected territory** – Bakhvi 2A HPP, Bakhvi 2B HPP (Guria region),
    - **Variable** – annual rainfall range,
    - **Period** – 2040-2059,
    - **Projection** – latest IPCC ensemble,
    - **Scenario** – RCP 6.0.

Climatic changes lead to changes in the hydrological regime of rivers, including the intra-annual distribution of flow, and this creates a problem of water supply in the economic sphere. In addition, in many countries, attention has recently increased significantly to the development of hydropower, which requires the calculation of flow characteristics.

Intra-annual runoff data are also needed to assess the balance of inflow and water consumption in the region.

According to natural observations, the annual distribution of flow of the Bakhvistskali River (more details - Table 11, 12) looks as follows:

Seasons	Bakhvistskali River
observation data (1955-2011)	
Spring	42%
Summer	35%
Autumn	15%
Winter	8%

Along with the projected changes in air temperature and precipitation in the study region, the distribution of water flow in the Bakhvistskali River during the year will also change but not significantly:

Seasons	Bakhvistskali River
RCP 6.0 climate change scenario (2040-2059)	
Spring	42%
Summer	36%
Autumn	14%
Winter	8%

According to forecasts for 2040-2059, the maximum amount of flow of the Bakhvistskali River will take place in spring. The percentage of winter flow will remain the same, flow during the summer will increase by 1%, and during the autumn will decrease by 1%. Such changes, even if they are not significant, need to be taken into account during the management of Bakhvi 2 HPP.

Table 11. Annual distribution of flow of the Bakhvistskali River (Bakhvi 2A HPP)

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Year
Flow	**observation data**												
water discharge, m^3/s	1.1	4	9.6	7.3	2.19	1.9	1.6	1.7	1.8	1.4	0.9	0.8	2.92
water flow volume, mln m^3	2.95	10.37	25.71	19.55	7.52	5.09	4.15	4.55	4.82	3.39	2.41	2.07	92.6
water flow volume per season, mln m^3	39.03			32.16			13.52			7.87			
share of water flow per season (%)	42.2			34.7			14.6			8.5			100
Flow	**projected data**												
water discharge, m^3/s	1.45	3.73	10.24	7.47	3.7	2	1.76	1.79	1.47	1.45	0.74	1.07	3.07
water flow volume, mln m^3	3.88	9.67	27.43	20.01	9.59	5.36	4.56	4.79	3.94	3.51	1.98	2.77	97.5
water flow volume per season, mln m^3	40.98			34.96			13.29			8.26			
share of water flow per season (%)	42			35.9			13.6			8.5			100

Table 12. Annual distribution of flow of the Bakhvistskali River (Bakhvi 2B HPP)

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Year
Flow	**observation data**												
water discharge, m^3/s	1.2	4.6	11.0	8.4	3.4	2.1	1.9	2.0	2.0	1.6	1.0	0.9	3.34
water flow volume, mln m^3	3.21	11.92	29.46	22.50	8.81	5.62	4.92	5.36	5.36	3.87	2.68	2.33	106.1
water flow volume per season, mln m^3	44.59			36.93			15.64			8.88			
share of water flow per season (%)	42.1			34.8			14.7			8.4			100
Flow	**projected data**												
water discharge, m^3/s	1.58	4.29	11.74	8.59	4.34	2.22	2.09	2.11	1.64	1.66	0.83	1.21	3.53
water flow volume, mln m^3	4.23	11.12	31.44	23.01	11.25	5.95	5.42	5.65	4.39	4.02	2.22	3.14	111.8
water flow volume per season, mln m^3	46.79			40.21			15.46			9.38			
share of water flow per season (%)	41.9			35.9			13.8			8.4			100

Task 3: Increased intensity and frequency of extreme floods

The **increased intensity and frequency of extreme floods** is determined by a complex range of possible situations, that typically associate rainfalls and snow melting events in Georgia.

Objective: to identify the plausible effect of climate change scenarios on extreme floods values. In the absence of readily available methodology for this assessment, the method for Task 3 follows the approximations recommended by the IHA, that consider the water holding capacity of the atmosphere as a function of temperature (Clausius-Clapeyron equation). For each 1ºC change in average atmospheric temperature, it is reasonable to increase the water holding capacity of the atmosphere by about 7% and to increase the design flood in proportion. In any case, it is not recommended to explore design flood reductions for future scenarios of global warming.

The **method for Task 3** is the following one:

- Access to regional climate change projections on the WBG's Climate Change Knowledge Portal.
  - **Selected territory** – Bakhvi 2A HPP, Bakhvi 2B HPP (Guria region),
  - **Variable** – monthly temperature,
  - **Period** – 2040-2059,
  - **Projection** – latest IPCC ensemble,
  - **Scenario** – RCP 6.0.

The intensity and frequency of the Bakhvistkali river floods were assessed according to IHA recommendations. Changes in average monthly and average annual air temperatures were taken into account. Given that an increase of 1ºC air temperature results in an increase in the water holding capacity of the atmosphere by 7%. Accordingly, a proportional increase in floods in the project perspective should be expected.

Prognosis of air temperature at the website CCKP is also done based on the reference period 1986-2005 (Figure 4).

Monthly temperature delta (delta_4) for Guria region between the reference period 1986-2005 and the projected period 2040-2059 presented in Table 13.

Table 13. Monthly temperature delta for Guria region

Parameter \ Month	Temperature, °C												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Guria historical (1986-2005)	-1.28	-0.49	2.54	7.34	12.05	16.36	19.36	19.26	15.26	9.94	4.53	0.49	8.78
Guria projected (2040-2059)	0.50	0.80	3.62	8.40	13.38	18.10	21.29	21.45	16.93	11.23	5.69	2.13	10.29

Parameter \ Month	Temperature, °C												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
delta_4 (°C)	1.78	1.29	1.08	1.06	1.33	1.74	1.93	2.19	1.67	1.29	1.16	1.64	1.51

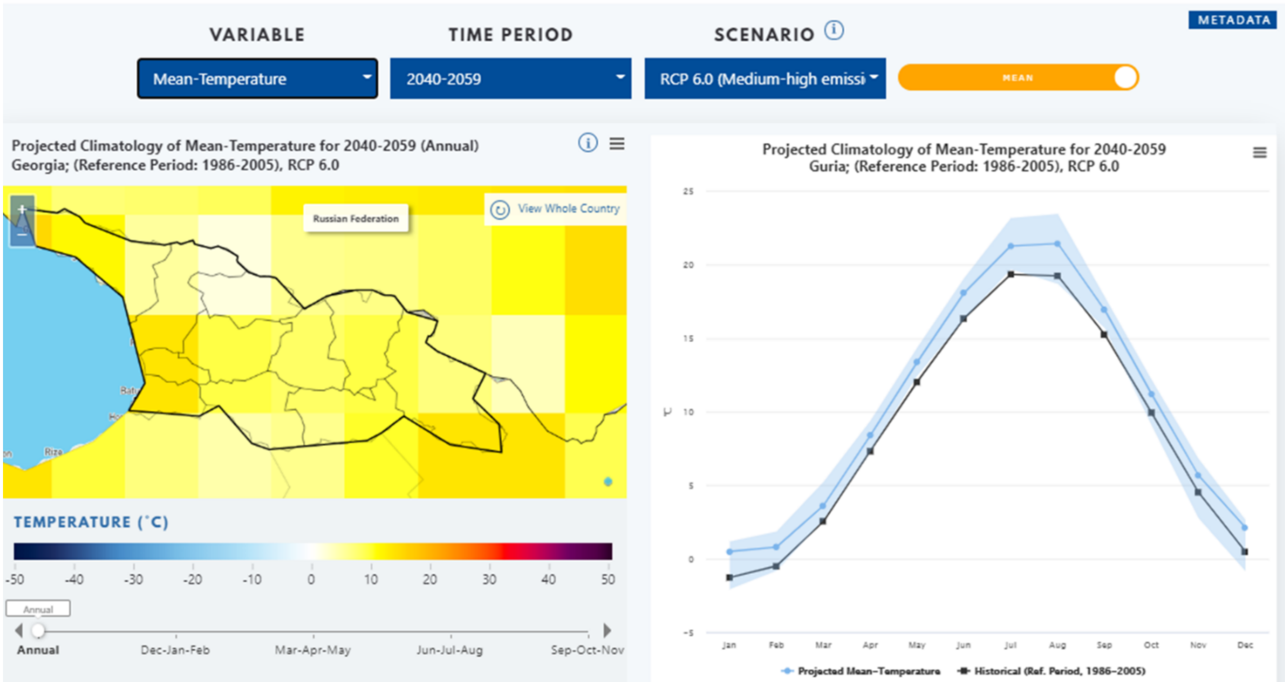

Figure 4. Climate Change Knowledge Portal (CCKP), temperature data

To determine the magnitude of the change in intensity and frequency of extreme floods for period 2040-2059, used the average monthly and average annual air temperatures according to the meteorological station Bahmaro resort (1986-2005), and delta_4 from Table 13 for the Guria region (Table 14).

Table 14. Average monthly and average annual air temperatures for period 2040-2059, °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Bakhmaro 1986-2005	-4.81	-5.16	-2.15	3.26	6.92	10.50	13.92	13.88	10.62	6.59	1.24	-2.81	4.41
delta_4 (°C)	1.78	1.29	1.08	1.06	1.33	1.74	1.93	2.19	1.67	1.29	1.16	1.64	1.51
Bakhmaro 2040-2059	-3.03	-3.87	-1.07	4.32	8.25	12.24	15.85	16.07	12.29	7.88	2.40	-1.17	5.92

According to the results of the calculations presented in Table 10 in 2040-2059 under the conditions of RCP 6.0 climate change scenario, the average annual air temperature is expected to increase by 1.5°C (from 4.4°C to 5.9°C) compared to the period 1986-2005.

Given that with a 1ºC increase in air temperature, we should expect a proportional increase in floods in the project perspective by 7%, in the project perspective in 2040-2059 under the conditions of RCP 6.0 climate change scenario intensity and frequency of floods will increase by an average of 10.6% (Table 15).

Table 15. Increased intensity and frequency of extreme floods for period 2040-2059

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Increased intensity and frequency of extreme floods, %	12.5	9.0	7.6	7.4	9.3	12.2	13.5	15.3	11.7	9.0	8.1	11.5	10.6

Most floods will occur in the summer season. The percentage of projected growth in the intensity and frequency of floods in the long term 2040-2059 in the summer months exceeds 12%.

Flood discharges and levels for different probabilities

Assessment of potential changes of water discharges for different probabilities for the period 2040-2059 is performed for water discharges (Q historical) received from the Client. The forecast (Q projected) is performed for different probabilities 0.2, 0.5, 1, 2, 10, 50% (Table 16, 17).

The forecast for Bakhvi 2A HPP and Bakhvi 2B HPP is based on:

- hydrological observations of maximum water discharge at the hydrological station in Kveda Bakhvi.
- meteorological observations of precipitation at the nearest meteorological station in the Bakhmaro resort.
- monthly precipitation projected data for the Guria region (according to CCKP).

The following coefficients were used in the calculations:

- coefficient, which takes into account reduction of the maximum water discharge and
- transition coefficient from maximum water discharges of annual probability of excess P, equals to 0.5% to maximum water discharge of another probability of excees.

Table 16. Results of calculations of maximum water discharges of river Bakhvi for Bakhvi 2A HPP intake and power house for period 2040-2059

<table>
<tr><td rowspan="10">Bakhvi 2A HPP intake</td><td>Probability, %</td><td>0.5</td><td colspan="2">1</td><td>2</td><td>10</td></tr>
<tr><td>Return period, year</td><td>200</td><td colspan="2">100</td><td>50</td><td>10</td></tr>
<tr><td>Q historical, m^3/s</td><td>172</td><td colspan="2">126</td><td>91</td><td>41</td></tr>
<tr><td>Q projected, m^3/s</td><td>186</td><td colspan="2">134</td><td>96</td><td>43</td></tr>
<tr><td>Difference, %</td><td>+8.1</td><td colspan="2">+6.3</td><td>+5.5</td><td>+4.9</td></tr>
<tr><td>Probability, %</td><td colspan="3">0.3</td><td colspan="2">1</td></tr>
<tr><td>Return period, year</td><td colspan="3">300</td><td colspan="2">100</td></tr>
<tr><td>H historical, m.a.s.l</td><td colspan="3">1381.30</td><td colspan="2">1380.85</td></tr>
<tr><td>H projected, m.a.s.l</td><td colspan="3">1381.53</td><td colspan="2">1381.03</td></tr>
<tr><td>Difference, %</td><td colspan="3">+0.017</td><td colspan="2">+0.013</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="10">Bakhvi 2A HPP power house</td><td>Probability, %</td><td>0.5</td><td colspan="2">1</td><td>2</td><td>10</td></tr>
<tr><td>Return period, year</td><td>200</td><td colspan="2">100</td><td>50</td><td>10</td></tr>
<tr><td>Q historical, m^3/s</td><td>193</td><td colspan="2">141</td><td>102</td><td>46</td></tr>
<tr><td>Q projected, m^3/s</td><td>208</td><td colspan="2">151</td><td>107</td><td>48</td></tr>
<tr><td>Difference, %</td><td>+7.6</td><td colspan="2">+7.1</td><td>+4.9</td><td>+5.2</td></tr>
<tr><td>Probability, %</td><td colspan="2">0.2</td><td colspan="2">1</td><td>50</td></tr>
<tr><td>Return period, year</td><td colspan="2">500</td><td colspan="2">100</td><td>2</td></tr>
<tr><td>H historical, m.a.s.l</td><td colspan="2">1066.50</td><td colspan="2">1064.65</td><td>1062.20</td></tr>
<tr><td>H projected, m.a.s.l</td><td colspan="2">1066.68</td><td colspan="2">1064.86</td><td>1062.43</td></tr>
<tr><td>Difference, %</td><td colspan="2">+0.017</td><td colspan="2">+0.020</td><td>+0.022</td></tr>
</table>

Table 17. Results of calculations of maximum water discharges of river Bakhvi for Bakhvi 2B HPP intake and power house for period 2040-2059

<table>
<tr><td rowspan="10">Bakhvi 2B HPP intake</td><td>Probability, %</td><td>0.5</td><td>1</td><td>2</td><td>10</td></tr>
<tr><td>Return period, year</td><td>200</td><td>100</td><td>50</td><td>10</td></tr>
<tr><td>Q historical, m^3/s</td><td>193</td><td>141</td><td>102</td><td>46</td></tr>
<tr><td>Q projected, m^3/s</td><td>208</td><td>151</td><td>107</td><td>48</td></tr>
<tr><td>Difference, %</td><td>+7.6</td><td>+7.1</td><td>+4.9</td><td>+5.2</td></tr>
<tr><td>Probability, %</td><td colspan="2">0.3</td><td colspan="2">1</td></tr>
<tr><td>Return period, year</td><td colspan="2">300</td><td colspan="2">100</td></tr>
<tr><td>H historical, m.a.s.l</td><td colspan="2">1060.60</td><td colspan="2">1060.35</td></tr>
<tr><td>H projected, m.a.s.l</td><td colspan="2">1060.76</td><td colspan="2">1060.57</td></tr>
<tr><td>Difference, %</td><td colspan="2">+0.015</td><td colspan="2">+0.021</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="5">Bakhvi 2B HPP power house</td><td>Probability, %</td><td>0.5</td><td>1</td><td>2</td><td>10</td></tr>
<tr><td>Return period, year</td><td>200</td><td>100</td><td>50</td><td>10</td></tr>
<tr><td>Q historical, m^3/s</td><td>210</td><td>154</td><td>111</td><td>50</td></tr>
<tr><td>Q projected, m^3/s</td><td>226</td><td>165</td><td>118</td><td>53</td></tr>
<tr><td>Difference, %</td><td>+7.5</td><td>+7.1</td><td>+6.4</td><td>+6.6</td></tr>
</table>

	Probability, %	**0.2**
	Return period, year	500
	H historical, m.a.s.l	506.40
	H projected, m.a.s.l	506.51
	Difference, %	**+0.021**

According to the results:

- for the Bakhvi 2A HPP – **water discharge** with the lowest probability of exceeding (0.5% of probability) for the period 2040-2059 will increase by 8.1 and 7.6% for the intake and power house, respectively; water discharge with the highest probability of exceeding (10% of probability) for the period 2040-2059 will increase by 4.9 and 5.2% for the intake and power house, respectively;
- for Bakhvi 2B HPP – **water discharge** with the lowest probability of exceeding (0.5% of probability) for the period 2040-2059 will increase by 7.6 and 7.5% for the intake and power house, respectively; water discharge with the highest probability of exceeding (10% of probability) for the period 2040-2059 will increase by 5.2 and 6.6% for the intake and power house, respectively;
- for the Bakhvi 2A HPP intake **water level** for the period 2040-2059 will increase by 0.017 (0.3% of probability) and 0.013 (1% of probability); for the Bakhvi 2A HPP power house for the period 2040-2059 will increase by 0.017 (0.2% of probability) and 0.022 (50% of probability);
- for the Bakhvi 2B HPP intake **water level** for the period 2040-2059 will increase by 0.015 (0.3% of probability) and 0.021 (1% of probability); for the Bakhvi 2B HPP power house for the period 2040-2059 will increase by 0.021 (0.2% of probability).

Task 4: Analytic conclusion and resilience measures definition

Objective: to analyse the outcomes of tasks 1 to 3, and draw an analytic conclusion regarding the exposure of the hydropower scheme to climate change.

Analysis of the results obtained for each area of assessment of the impact of potential climate change on the hydrological regime and electricity production in 2040-2059 under the RCP 6.0 scenario allows us to draw the following conclusions:

- the average annual water availability with 50% provision in 2040-2059 in the Bakhvi 2A HPP headwork will increased by 0.15 m^3/s, in Bakhvi 2B HPP headwork – by 0.19 m^3/s;
- annual energy generation calculated for the period 2040-2059 for Bakhvi 2A HPP – 47.41 GWh (increased by 4.1%), for Bakhvi 2B HPP – 96.75 GWh (increased by 4.2%);
- the intensity and frequency of floods will increase by 10.6% on average, most floods will occur in the summer season.

As an adaptation to the long-term consequences of climate change and their impact on the hydrological regime and electricity production in 2040-2059 under the RCP 6.0 scenario, the following measures can be identified:

It is recommended to develop database, which include the data from meteorological station Bakhmaro and data of hydrological station at Bakhvi 2A and Bakhvi 2B (intake) and analyse the obtained data monthly and yearly.

Data from meteorological station: **air temperature** and **precipitation**.

Data from hydrological station: **water level** and **water discharge.**

Collected information can be used during studies of impact of climate change in the future.

Conclusions

According to the methodology provided by the Client, an assessment of the possible impact of climate change on the electricity production of Bakhvi 2A HPP and Bakhvi 2B HPP was carried out.

The assessment is based on observations at meteorological and hydrological stations, using projections of future climate change on CCKP.

Analysis of the results obtained for each area of assessment of the impact of potential climate change on the hydrological regime and electricity production in 2040-2059 under the RCP 6.0 scenario allows us to draw the following conclusions:

- during the period of long-term observations, the average annual precipitation in the Guria region was 953 mm. In the period 2040-2059 precipitation is expected with an average layer of 997 mm per year;
- the average annual water availability with 50% provision in 2040-2059 in the Bakhvi 2A HPP headwork will increased by 0.15 m^3/s, in Bakhvi 2B HPP headwork – by 0.19 m^3/s;
- annual energy generation calculated for the period 2040-2059 for Bakhvi 2A HPP will increased by 4.1%, for Bakhvi 2B HPP – by 4.2%;
- under the conditions of RCP 6.0 climate change scenario, the average annual air temperature for Guria region is expected to increase by 1.5°C (from 4.4°C to 5.9°C) compared to the period 1986-2005;
- the intensity and frequency of floods will increase by 10.6% on average, most floods will occur in the summer season;

The results of the assessment and recommendations for reducing the possible impact of climate change on electricity production in the future can be used in the management of Bakhvi 2A HPP and Bakhvi 2B HPP.