NVE

Runoff map of Georgia

Hydrological modelling of water balance

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REPORT

Runoff map of Georgia

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Summary: A map of 30-year mean annual runoff for Georgia is a major result of the project 'Institutional Cooperation between Ministry of Energy and the National Environmental Agency of Georgia, and the Norwegian Water Resources and Energy Directorate'. The overall goal of the project is to make reliable assessments of hydropower energy resources in Georgia. The runoff map is determined using results from a spatially distributed hydrological model that simulates the water balance for the entire land surface of Georgia and upstream areas in neighbour countries.

Keywords: runoff map, hydrological model, meteorology, hydrology, water balance

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Preface

Assessment of water resources available for hydropower development is the purpose of the project 'Institutional Cooperation between Ministry of Energy (MOE) and the National Environmental Agency (NEA) of Georgia, and the Norwegian Water Resources and Energy Directorate (NVE)' running for the period 2013-2016. Georgia has a large hydropower potential, which when developed will cover the need for domestic as well as industrial use of energy. In addition, the surplus energy may be exported to neighbouring countries and contribute to the economic development in Georgia. Therefore, the strategy of MOE is an optimum, but at the same time sustainable, development of the hydropower resources that Georgia possesses. For this purpose, MOE provides potential investors with the data for the construction of new hydropower plants. Besides, it is essential to identify and explore new opportunities on a national scale. The hydrological data necessary for the assessment have been obtained from NEA. Unfortunately, most of the hydro-meteorological data existed only on paper when the project started and could not be used directly as input to modern software and analyses tools. In 1989 most of the hydro-meteorological services in Georgia broke down and has only recently partly been re-established. In frame of the project historical meteorological and hydrological data were digitized and are now available in the database systems at NEA. A map of mean annual runoff for the period 1961-1990 for Georgia is a major result of the project. Runoff is the quantity of water that discharges to river and stream channels, lakes or directly into the ocean, and it includes both surface and subsurface flow of water. For a period of several years changes in the amounts of water stored in lakes, snow and subsurface water are usually minor and runoff equals the amount of precipitation remaining after losses of water to the atmosphere by evaporation and transpiration processes. The runoff map is determined using results from a spatially distributed hydrological model that simulates the water balance with daily time resolution for the entire land surface of Georgia and upstream areas of watersheds in neighbour countries draining to Georgia. The hydrological model requires observed meteorological and hydrological data with high quality and high spatial resolution in order to supply reliable results.

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Summary

Estimation of runoff discharging to rivers and streams is a requirement for assessment of water resources available for hydropower production, irrigation and water supply. A map of 30-year mean annual runoff for Georgia is a major result of the project ‘Institutional Cooperation between Ministry of Energy and the National Environmental Agency of Georgia, and the Norwegian Water Resources and Energy Directorate’ running for the period 2013-2016. Runoff is the quantity of water that discharges to river and stream channels, lakes or directly into the ocean, and it includes both surface and subsurface flow of water. For a period of several years changes in the amounts of water stored in lakes, snow and subsurface water are usually minor and runoff equals the amount of precipitation remaining after losses of water to the atmosphere by evaporation and transpiration processes. The exceptions are areas covered with glacier ice where the ablation or accumulation of ice results in changes in the amounts of storage. The map shows local runoff for a spatial resolution of one by one square kilometres in units of millimetres of water per year. Total runoff from a watershed equals the accumulated sum of runoff from the individual one square kilometre elements draining to the outlet. The runoff map is determined using results from a spatially distributed hydrological model that simulates the water balance with daily time resolution for the entire land surface of Georgia and upstream areas of watersheds in neighbour countries draining to Georgia. The hydrological model requires observed meteorological and hydrological data with high quality and high spatial resolution in order to supply reliable results. As the station network of meteorological and hydrological data deteriorated during the years after 1990 the period 1961-1990 was used for production of the runoff map. The hydrological model used meteorological data from 249 precipitation stations and 119 temperature stations from Georgia and upstream areas in neighbour countries. The model was set up using streamflow data from 160 hydrological stations located at the outlet of watersheds all over Georgia. The model is sensitive to spatial variability of the properties of the land surface and the meteorological input data through explicit representation of data characterizing the model domain, e.g. elevation, soil type, geology, vegetation, lakes, wetlands, glaciers, precipitation and temperature. The runoff map shows the important features of the hydrological regimes of Georgia, with humid subtropical climate of the Black Sea and steppe-continental climate of eastern Georgia, and the impacts of high elevation areas in the Caucasus mountain ranges on meteorological and hydrological processes.

1 Introduction

The Ministry of Energy (MOE) of Georgia is in charge of coordination of development of the hydropower potential in the country in order to attract investors for construction of new hydropower plants. The National Environmental Agency (NEA), under the Ministry of Environment and Natural Resources Protection, is responsible for all water resources monitoring and management in Georgia, and prepares and distributes the information concerning hydro-meteorology, water reserves and the Black Sea territorial waters. The Norwegian Water Resources and Energy Directorate (NVE) is responsible for ensuring an integrated and environmentally sound management of Norway's water resources, as well as promoting efficient energy markets and cost-effective systems and contributing to efficient energy use. MOE, NEA and NVE have been engaged in the project 'Institutional Cooperation between Ministry of Energy and National Environmental Agency of Georgia, and Norwegian Water Resources and Energy Directorate running for the period 2013-2016.

The climate of Georgia is characterized by great diversity. Almost all types of climate regimes are represented here, with the exception of desert, savanna and tropical forests. The Likhi range, passing through the centre of the country, divides the territory into two regions with dramatically differing climate, humid subtropical in western Georgia and mainly dry subtropical in eastern Georgia. In the lowlands of western Georgia and the Black Sea coastal zone, mean annual temperature is approximately 14-15 °C, and annual precipitation varies in the range of 1500-2700 mm. The alpine zone of the same region contains mountain massifs included in the Greater Caucasus, covered with permanent snow and glaciers, the height of which is more than 5000 metres above sea level. In the plains of eastern Georgia mean annual temperature is up to 11-13 °C and annual precipitation is around 400-600 mm, in the mountainous regions annual precipitation increases up to 800-1200 mm. During the last 25 years, under the impact of global warming, mean annual temperature in western Georgia increased by 0.3 °C, and in eastern Georgia the increase was 0.4-0.5 °C. The total annual runoff of rivers in western Georgia three times exceeds that of rivers in eastern Georgia. Over 600 glaciers with total area of 356 km^2 and approximate ice volume of 20 km^3 are currently registered on the territory of the country. About 850 small lakes and over 40 reservoirs with irrigation and hydropower production are registered on the territory of the country (Ministry of Environment and Natural Resources Protection of Georgia, 2015).

Georgia has a large hydropower potential, which when developed will cover the need for domestic as well as industrial use of energy. In addition, the surplus energy may be exported to neighbouring countries and contribute to the economic development in the country. Therefore, the strategy of the MOE is an optimum, but at the same time sustainable, development of the hydropower resources that Georgia possesses. For this purpose, MOE provides potential investors with the data for the construction of new hydropower plants. Besides, it is essential to identify and explore new opportunities on a national scale. A thorough knowledge on the water resources is not only vital, but a prerequisite for the hydropower assessment and development. The hydrological data necessary for the assessments have been obtained from NEA. Unfortunately, most of the hydro-meteorological data existed only on paper when the project started and could not be used directly as input to modern software and analyses tools. In 1989 most of the hydro-meteorological services in Georgia broke down and has only recently partly been re-established (2006). In frame of the project historical meteorological and hydrological data were digitized and is now available in the database systems at NEA. Today, other cooperation programs are re-establishing the physical station network including automatic transfer of water and weather data. It is important to ensure operational good routines for collection, control, storage and analysis of hydrological data. An operational hydrological computer system with necessary analyses tools, will in the future benefit all water users and will highly facilitate a future introduction of the EU Water Framework Directive.

The overall goal of the project is to make reliable assessments of hydropower energy resources in Georgia based on a map of mean annual runoff. Runoff is the quantity of water that discharges to river and stream channels, lakes or directly into the ocean, and it includes both surface and subsurface flow of water. For a period of several years changes in the amounts of water stored in lakes, snow and subsurface water are usually minor and runoff equals the amount of precipitation remaining after losses of water to the atmosphere by evaporation and transpiration processes. The runoff map is determined using results from a spatially distributed hydrological model that simulates the water balance with daily time resolution for the entire land surface of Georgia and upstream areas of watersheds in neighbour countries draining to Georgia. Once the model has been set up it can also be run used for other purposes that requires assessment of hydrological processes and water resources. The hydrological model requires observed meteorological and hydrological data with high quality and high spatial resolution in order to supply reliable results and quality control of data is therefore an important activity in the project.

The staff of Hydro-meteorological division at NEA is considered as highly competent, but was suffering from lack of capacity when the project started, in particular as the old station network is rehabilitated and new stations are established. There was also a need to carry out training and increase the competence level in some fields. The establishment of a runoff map for the whole of Georgia necessitated training and increase of competence. Land surface characteristics and terrain elevation from GIS and meteorological and hydrological time series has been used for setting up and running a nationwide hydrological model that characterizes the runoff and other hydrological elements of Georgia. The hydrological model was set up and run in cooperation with NEA. Model results for runoff has been used as input to a GIS-based expert system for evaluation of hydropower potential and hydropower plant construction costs.

The staff at NEA lacks competence in doing hydrological modelling. Participation in the whole process, including the modelling, was therefore considered important when the project started. Establishment of the runoff map should therefore be a combination of workshops and on-the-job training. The same partly applies to the establishment of the digital terrain model including land cover data. Some of this information is already available at NEA, but it all need to be put together for use in the hydrological model, and this should be done as a joint effort between NVE and NEA, combined with workshops and on-the-job training.

The final part of the project, the computation of the hydropower potential and the prioritization of the various schemes according to costs in a GIS-system, is not described in this report. When this work is successfully completed, the MOE will possess a very valuable tool for development of the hydropower resources of the country.

In short, the end results of the project are:

- All existing hydro-meteorological data in electronic form
- All hydrological data quality controlled
- A runoff map covering the whole of Georgia
- An operational nationwide hydrological model
- A GIS-based model for assessment of the total hydropower potential of Georgia, including development costs.
- Well trained staff at NEA and MOE

The priority target groups of the project are MOE and NEA, which have received improved and more efficient tools for monitoring and management of the water resources. Their staff received training, and transfer of knowledge was an important part of the project. Besides these main target groups, all users of hydro-meteorological data have benefited from the project. Hydro-meteorological data of good quality are necessary for planning of hydropower production, irrigation, water supply, pollution control, flood and drought forecasting, etc.

2 Characterization of Georgia

2.1 Geographical features of Georgia

Georgia is located in Southern Caucasus in the mid-latitude area. The capital city is Tbilisi and the population as of January 1st 2014 was 4.51 million inhabitants, excluding the population of the occupied territories of Abkhazian Autonomous Republic and Tskhinvali region. The length of the state borders is 2 148 km of which land borders are 1 839 km. The country is bordered by the Russian Federation in the north, Azerbaijan in the southeast, Armenia and Turkey in the south, and the Black Sea in the west.

The territory of Georgia occupies the central and western part of Southern Caucasus, its area is 69 700 km^2. 18 200 km^2 (26.1% of the whole territory) is below 500 metres above sea level, 13 900 km^2 (19.9%) is between 500 and 1000 metres above sea level, 24 100 km^2 (34.6%) is between 1000 and 2000 metres above sea level, and 13 500 km^2 (19.4%) is above 2000 metres above sea level. Mountains occupies 55% of the country, foothills 32% and lowlands only 13%. The main mountain ranges in Georgia are listed in Table 2.1.

Table 2.1. Main mountain ranges in Georgia

Main mountain ranges			Highest peaks		
Name	Elevation, metres above sea level	Peak coordinate	Name	Elevation, metres above sea level	Coordinate
Caucasus	5068	Shkhara 43.01°N 43.17°E	Shkhara	5068	43.01°N 43.17°E
Khorkhi	5047	Mkinvartsveri 42°41′51″N 44°31′08″E	Jangha	5058	43.01889°N 43.05671°E
Piriqiti	4494	Tebulos-Mta 42.64°N 45.32°E	Mkinvartsveri (Kazbegi)	5047	42°41′51″N 44°31′08″E
Kuro	4048	Shino 42°38′42″N 44°42′46″E	Katyn-Tau	4979	43.03069°N 43.03555°E
Svaneti	4009	Lahili 42°55′31″N 42°33′06″E	Shota Rustaveli	4960	43.02592°N 43.04349°E
Lechkhumi	3580	Samerckhle 42°42′54″N 43°10′60″E	Gistola	4859	43°02′51″ N 43°01′33″ E
Gudisi	3339	42°27′08″N 44°11′06″E	Tetnuldi	4851	43.03113°N 42.99319°E
Kodori	3313	Khojali 41°59′02 N 44°52′06″E	Ushba	4695	43.12486°N 42.65901°E
Samsari	3301	Didi Abuli 41°26′17″ N 43°38′45″E	Tebulos-Mta	4494	42.64°N 45.32°E
Gagra	3295	Agebsta 43°32′53″N 40°28′53″ E	Chanchakhi	4462	42°44′48″N 43°47′35″E
Likhi	2471	Ribisi 42°25′56″ N 43°45′27″E	Babismta	4454	43°11′40″N 42°30′53″E.

The mountainous relief determines the diversity of Georgia’s physical geography. The Likhi (Surami) sub-meridian range connects the Greater Caucasus and the Lesser Caucasus mountain ranges. In spite of its relatively low altitude (elevation between 900 and 2471 metres above sea level), the Likhi range acts as a climatologically dividing barrier. Western Georgia is characterised by the slopes of the Greater Caucasus, Likhi and Meskheti ranges, descending to the Black Sea like a gigantic amphitheatre, where the Kolkhida lowland forms a triangle in the lower part of the Rioni River. The central part of eastern Georgia is occupied by the valley of the Mtkvari (Kura) River, descending uniformly from the Likhi range eastwards. To the north, also the southern slopes of the Greater Caucasus are descending to this valley. Figure 2.1 shows physical map of Georgia.

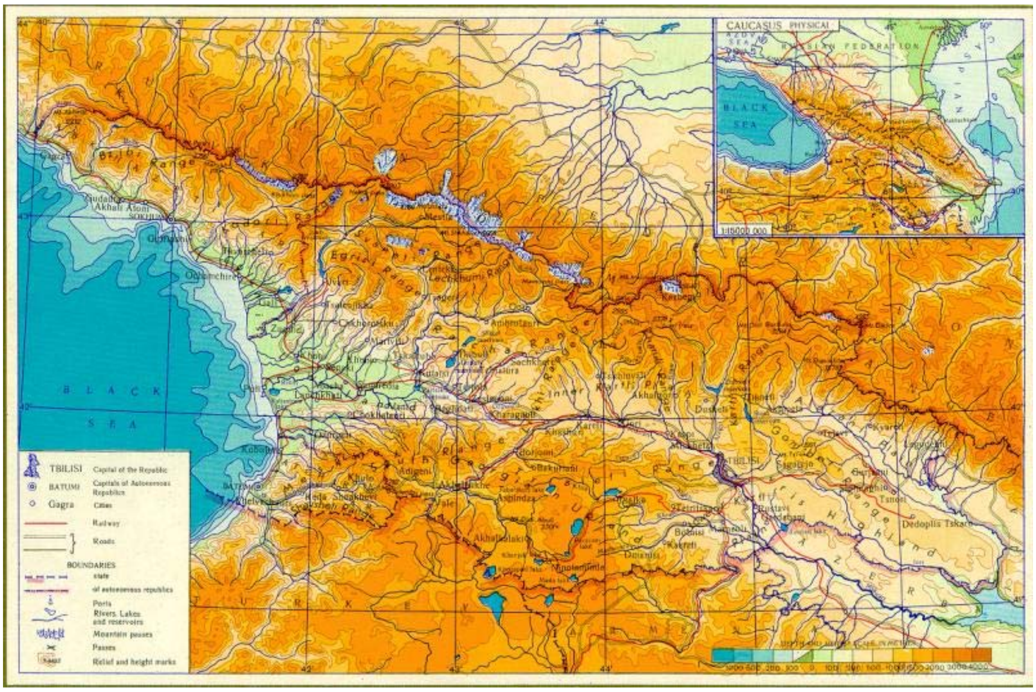

Figure 2.1. Physical map of Georgia

The geographical position of Georgia between the Black Sea and the arid regions lying to the East, including both the Greater and Lesser Caucasus determines the peculiarities of the relief and the great variety of nature. The climate of Georgia is particularly diverse, from perennial snow and glaciers of the Greater Caucasus high mountain zone to a humid subtropical climate of the Black Sea and steppe-continental climate of eastern Georgia. Most types of global climate zones can be found in Georgia, except for tropical, arid and savannas.

The zonal direction of the Caucasian mountain ranges directs air masses in western and eastern directions. Abrupt changes of the weather are due to the air masses invading from these two directions, divided by the meridional stretching Likhi range. The Greater Caucasus mountain range is an almost unsurmountable obstacle for the northern winds. The Lesser Caucasus mountain range hold back the southern winds in the lower atmospheric layers, while air masses are moving more freely at higher levels.

Another major factor influencing the climatic regimes of the country is the particular combination of solar radiation and local atmospheric circulation. Being located in the subtropical belt Georgia enjoys a long duration (over 2 000 hours per annum) of sunshine of high intensity.

Local air circulation, differences in the heating of land and sea, mountain ranges, plateaus and valleys contribute to local thermal air circulation which, in turn, influences mountain-valley and shore (breeze and monsoon) circulation, inducing turbulent and convective air currents which lead frequently to thunderstorms, heavy precipitation and hail.

2.2 Water resources

In Georgia there are 26 060 rivers and stream with a total length of 60 000 km. They belong both to the Caspian and Black Sea basins. 25 075 (99.4%) of the rivers are small (less than 25 km length), with total length of 54 768 km. More than 18 109 (70%) of the rivers belong to the Black Sea basin, and 7 951 (30%) belong to the Caspian Sea basin. The rivers of western Georgia flows directly into to the Black Sea. The annual runoff generated within the territory of Georgia is 56.9 km^3, the amount of inflow is 9.4 km^3, and thus the total amount of annual runoff from Georgia is 66.3 km^3. The main rivers of Georgia are listed in Tables 2.2 and 2.3.

Table 2.2. The main rivers (from north to south) of the rivers draining to the Black Sea

River name	Length (km)	Catchment area (km^2)
Psou	53	426
Bzibi	115	1 502
Inguri	221	4 062
Tskhenistskali	183	2 122
Rioni	327	13 418
Kodori	84	2 030
Acharistskali	90	1 540
Choroki	438*	22 132*

The Choroki River origins in Turkey, 31 km of the river length and 2 108 km^2 of the catchment area is inside Georgia. The Psou River forms the border between Georgia and the Russian Federation.

The Mtkvari (Kura) River is the longest river passing through Georgia, with total length of 1384 km of which 351 km is in Georgia. It originates in Turkey, crosses eastern Georgia and flows into Azerbaijan, and afterwards into the Caspian Sea. The total drainage area of the catchment is about 200 000 km^2 with 30 000 km^2 in Armenia, 56 000 km^2 in Azerbaijan, 5 500 km^2 in Turkey, 46 000 km^2 in Georgia, and 63 000 km^2 in Iran.

The rivers in Georgia are fed by precipitation, groundwater flow, drainage from wetlands and swamps, and meltwater from glaciers and snow.

Table 2.3. The main rivers (from north to south) draining to the Caspian Sea

River name	Length (km)	Catchment area (km^2)
Terek	71	778
Tusheti Alazani	59	869
Mtkvari (Kura)	351	23 000
Didi Liakhvi	115	2 311
Ksani	91	885
Aragvi	112	2 724
Paravani	81	2 278
Algeti	128	764
Iori	183	4 650
Alazani	385	11 800
Debed	35	210

The rivers Terek, Andiyskoye, Kura, Alazani, Iori and Debed are transboundary rivers.

In Georgia there are about 850 lakes, most of them are very small. The total area of lakes are 170 km^2 which represents 0.24% of total area of country. More than half of the lakes have area less than 0.1 km^2.

The major sources of inflow to the lakes can be specified as: meltwater from glaciers and snow (lakes located higher than 2500 metres above sea level), including the lakes Aduedaadzishi, Levanistba, Oqrostskali; precipitation, including the lakes Didi Bebisiri, Patara Bebiseri, Inkiti, Aliani etc; groundwater flow, including the lakes Paravani, Tabatskuri, Kartsakhi, Kakhisistba, Kelis; river flow, including the lakes Ritsa, Patara Ritsa, Khanchali, Saghamo, Madatapha; and precipitation and drainage from wetlands and swamps, including the lakes Paliastomi, Patara Paliastomi, Grigoleti. The water of lakes are suitable for drinking, their mineralization, in all season do not exceed 500-700 mg/l. Exceptions are the Kura-Alazani lakes, where mineralization in some seasons reach 2000-2500 mg/l. The major lakes of Georgia are listen in Table 2.4.

Table 2.4. Major lakes of Georgia

Name	Elevation, metres above sea level	Area of lake, km²	Catchment area, km²	Maximum depth, metres	Average depth, metres	Volume, mill. m³
Amtkeli	512	0.58	153	65.0	29.6	180.5
Bazaleti	878	1.22	14.4	7.0	4.5	5.55
Bareti	1621	1.34	9.3	1.3	0.82	1.1
Didi Bebesiri	15.9	0.61	17.5	4.5	2.3	1.4
Didi Oqrotskali	2421	0.1	2.2	26.5	12.0	1.2
Grdzeli	1584	0.08	0.41	3.9	2.02	1.63
Kartsakhi	1799	26.3	158	1.0	0.73	19.3
Lamazi	2808	0.11	1.48	16.5	11.4	1.25
Lisi	624	0.47	16.1	4.0	2.6	1.22
Madaphata	2108	8.78	136	1.7	1.08	9.5
Mrude	2184	0.26	7.8	8.3	5.3	1.42
Didi Mtsra	2184	0.15	1.66	42.0	17.9	2.68
Paliastomi	-0.3	18.2	547	3.2	2.6	52.0
Pharavani	2073	37.5	234	3.3	2.42	90.8
Phartotskali	-0,3	0,21	1,17	3,5	2,1	4,41
Didi Ritsa	884	1,49	155	101	63,1	94,0
Patara Ritsa	1235	0,10	2,95	76,0	33,8	3,25
Saghamo	1996	4,81	528	2,3	1,6	7,7
Tabatskuri	1991	14,2	83,1	40,2	15,5	221
Tobavarchkhili	2650	0,21	1,12	35,0	15,8	3,31
Khanchali	1928	13,3	176	0,8	0,48	6,4
Didi Tsitelikhati	2779	0,23	2,42	53	19,3	4,56
Nurgeli	1568	0,12	0,32	3,3	1,82	2,18
Keli	2914	1,28	7,56	63,0	27,8	31,7

In Georgia there more than 600 glaciers with total area of 356 km^2 and approximate ice volume of 20 km^3. Most of the glaciers are concentrated in western Georgia (67.3% of the total number and 81.2 % of the total area). The lowest elevations of glaciers are changing from western to eastern Georgia; The glaciers in the Bziphi basin are extending down to 2600 metres above sea level, in Enguri and Rioni basins glaciers are extending down to 2970-2990 metres above sea level, and in eastern Georgia glaciers are extending down to 3200-3340 metres above sea level (Didi Liakhvi, Aragvi, Tergi, Asa, Piriqetis Alazani river basins). Most of the glaciers have a small area of about 1 km^2, but nine glaciers are larger than 10 km^2. These are Chalaati (12.1 km^2), Lekhziri (35.0 km^2), Tviberi (24,7 km^2), Kvitlodi (12.1 km^2), Tsaneti (28.9km^2), Khalde (10.5 km^2), Adishi (10.2 km^2), Qvishi (19.3 km^2), and Suatisi (11.1 km^2). The characteristics of the glacier covered regions and river basins in Georgia are listen in Table 2.5.

Table 2.5. Characteristics of the glacier covered regions and river basins in Georgia

Region or river basin	Number of glaciers	Area of glaciers, km^2	Volume of glaciers, km^3	Elevation of firn lower point, metres above sea level	Elevation of firn upper point, metres above sea level
Bziphi	16	7.8	0.185	2600	3030
Kelasuri	3	1,5	0,030	2737	3043
Kodori	141	59,9	1,554	2760	3160
Enguri	250	288,3	22,462	2980	3420
Khobi	7	1,6	0,037	2435	3030
Rioni	124	62,9	2,161	2970	3500
Didi Liakhvi	22	6,6	0,128	3030	3270
Aragvi	6	1,63	0,028	3195	3420
Tergi	106	68,0	3,336	3346	3834
Asa	10	3,78	0,073	3212	3212
Arghuni	16	2,09	0,016	3595	3676
Piriqetis Alazani	33	7	0,115	3339	3658
Total	165	80.87	30.13		

Wetlands and swamps occupy 2 560 km^2, of which 2 250 km^2 is situated in the territory of western Georgia. However, most have dried out and presently wetlands and swamps occupy only the coastal part of the Kolkheti lowland in western Georgia with total area 627 km^2. The major characteristics of the wetlands and swamps in the Kolkheti lowland are listen in Table 2.6.

Table 2.6. Major characteristics of the wetlands and swamps in the Kolkheti lowland

Name	Location	Elevation, metres above sea level	Average depth, metres	Area, km²
Eritskali	Between the coast and dune	1,5	1,0	15
Phichora-Qvishona	Between rivers Isareta and Gagida	4,0	2,0	13,2
Eritskali	Between rivers Oqumi and Gagida	0,5-1,8	1,0	117
Torsa	Coastal plains	80,5	1,0	9,0
Nakarghali	Enguri River mouth	4,0	1,5	21,0
Tchuria	Between rivers Enguri and Khobi	3,0	0,8	90,0
Tchaladidi-Poti	Between rivers Rioni and Khobi	12,5	1,5	144
Qveshaneti	Qvesheti River shoreline	8-9	1,0	1,0
Morchkhili	Morchkhili River shoreline	5-9	1,0	1,0
Tchintaghele	Morchkhili River shoreline	5-9	1,1	1,4
Pichora-Paliastomi	Phichora River shoreline	0,5-1,8	8,0	191
Laituri	Basin of Shara River	1,5	2,0	1,2
Ispani 1 and Ispani 2	Basins of rivers Choloqi and Ochkhamuri	1,5	2,0	19,0
Natanebi - Sufsa	Between rivers Natanebi and Supsa	0,5-1,5	7,0	15,0

Hydrogeological zoning of Georgia is identified by five main artesian aquifer zones: Greater Caucasus critical substrate groundwater; pressured water system of Greater Caucasus southern slope; Georgian belt artesian basin; pressured water systems of Adjara-Trialeti folded mountain; and Artvini-Bolnisi belt.

The groundwater resources in Georgia equal to 21.7 km^3, which represents 43% of the annual runoff from the country's total area and 23% of the annual precipitation. The recourses are distributed unequally, with 65% in western Georgia, 25% in eastern Georgia and 13% in southern Georgia.

According to mineralization and temperature groundwater is divided into the following groups: fresh drinking water (mineralization not exceeding 1.0 g/l); mineral water (mineralization exceeding 1.0 g/l; thermal waters for healing (temperature 20˚C - 35˚C; and geothermal (40˚C - 108˚C).

The Georgian coastal zone bordering the Black Sea has a length of 330 km from the mouth of the Psou River (border with Russian Federation) to Kelenderi Cape (border with Turkey). The costal line is almost rectilinear with three distinct capes, Bichvinta, Sokhumi and Kodori. The shore line of the coastal zone can be divided into three categories:

- Precipice, mountainous, hilly and landslide with low capes, from Psou to Sokhumi
- Swamped and sandy, from Sokhumi to Qobuleti
- Precipice in some places, but mostly flat, from Qobuleti to Kelenderi

The characteristic of the coastal zone and the influence of local winds determine the wave patterns. Wave heights of one metre with maximum heights of five to six metres are often observed. During storms the wave heights reach 10 metres at the precipice shores and the spray heights reaches 20 to 30 metres.

The sea level of the Black Sea varies seasonally, the maximum sea level occurs is in June and the minimum in October. The annual amplitude of approximately 20 cm is influencing river water inflow to the Black Sea due to backwater effects at the outlet of the rivers. Due to tidal ebb and flow the diurnal sea level varies with approximately 10 cm, and due to seiches the sea level has an amplitude of approximately 15 cm. The average salinity of surface layer of the Black Sea varies from 17.5‰ in summer to 18‰ in winter.

In Georgia there are about 45 reservoirs, with 3.3 km^3 total capacity and 163 km^2 total area. The reservoirs are mainly used for irrigation and electricity production in hydropower plants (HPP) in addition to water supply and recreation. All reservoirs have a flood control function, and most of the reservoirs are used for seasonal and annual regulation of river runoff. In Georgia there are 12 large HPP reservoirs with 2.4 km^3 total capacity and 107 km^2 total area. The total capacity represents 5.1% of annual runoff in Georgian rivers. The Jvari dam reservoir in Enguri River in western Georgia has a capacity of 1.1 km^3, and area of 13.5 km^2 and it is the world's third highest dam with 271.5 metres elevation. For the purpose of irrigation about 30 dams with a total capacity of 1 km^3 have been built, mainly in eastern Georgia. The three largest irrigation reservoirs are all on the Iori River: the Sioni reservoir (0.3 km^3), the Tbilisi reservoir (0.3 km^3) and the Dalimta reservoir (0.18 km^3).

The largest reservoir in Georgia is Lake Tsalka (33.7 km^2), which is situated on the Khrami River valley, at an altitude of 1506 meters; the deepest reservoir (226 metres) is Gali-Jvari reservoirs cascade. The Tbilisi Sea reservoir is important for water supply to the city of Tbilisi, irrigation, fishing, and water sports. Its volume is 308 million m^3, its maximum depth is 45 metres, and its sources of water are the Iori River and Jinvali reservoir. The major reservoirs of Georgia are listed in Table 2.7.

Table 2.7. Major reservoirs of Georgia

Name of dam	Administrative unit	Nearest city	River name	Major basin	Sub-basin	Completed and/or operational since	Dam height (m)	Capacity (mill.m^3)	Area (km^2)	Irrigation	Water supply	Flood control	Hydroelectricity	Recreation
JVARI	SAMEGRELO ZEMO SVANETI	TSALENJIKHA	ENGURI	ENGURI	ENGURI	1978	271.50	1 110	13.31	X		X	X	
GALI	ABKHAZIA AR	GALI	ERIS-TSKALI, ENGURI	ENGURI	ERIS TSKALI	1972	64.55	145	8		X	X	X	
SHAORI	RAHA-LECHKHUMI AND KVEMO SVANETI	AMBROLAURI	DIDI-CHALA, SHAORA	RIONI	DZEVRULA	1955	14.20	90	11.8		X	X	X	
LAJANURI	RAHA-LECHKHUMI AND KVEMO SVANETI	TSAGERI	TSKHENISTSKALI, LAJANURI	RIONI	TSKHENISTSKALI	1960	69.00	25	1.5			X	X	
GUMATI	IMERETI	TSKALTUBO	RIONI	RIONI	RIONI	1958	30.00	39	3.12			X	X	
VARTSIKHE	IMERETI	TSKALTUBO	RIONI, KVIRILA, KHANIS-TSKALI	RIONI	KVIRILA	1976	10.00	4. 6	5.07			X	X	X
TKIBULI	IMERETI	TKIBULI	TKIBULA	RIONI	DZEVRULA	1956	36.00	84	12.1			X	X	X
KUKHI	IMERETI	KHONI	KUKHIS-TSKALI	RIONI	GUBIS TSKALI	1978	19.40	1.9	0.3	X		X		
ZAGESI	MTSKHETA MTIANETI	MTSKHETA	KURA, ARAGVI	KURA	ARAGVI	1927	24.00	12	2			X	X	
ERESI	SAMTSKHE-JAVAKHETI	AKHALKALAKI	KIRKH-BULAK, PARAVANI	KURA	PARAVANI	1976		2. 1	1.77	X		X		
TSKHNISES-CHA	SAMTSKHE-JAVAKHETI	ADIGENI	ZAZALOS-KHEVI	KURA	ZAZALOS-KHEVI	1969		1. 5	0.3	X		X		
NADARBAZEVI	SHIDA KARTLI	GORI	LIAKHVI	KURA	LIAKHVI	1966		8. 2	2	X		X		
PATARA-LIAKHVI (ZONKARI)	SHOUTH OCETI	TSKHINVALI	PATARA LIAKHVI	KURA	LIAKHVI	1985	69.00	40	1.4	X		X		
JINVALI	MTSKHETA MTIANETI	DUSHETI	PSHAVIS ARAGVI	KURA	ARAGVI	1985	102.00	520	11.52	X	X	X	X	
HAREKVAVI	MTSKHETA MTIANETI	DUSHETI	HAREKVAVI	KURA	ARAGVI	1978	41.00	6.8	0.5	X		X		
ALGETI	KVEMO KARTLI	TETRITSKARO	KURA, ALGERI	KURA	ALGETI	1983	86.00	65	2.3	X		X		
MARABDA	KVEMO KARTLI	TETRITSKARO	ALGETI	KURA	ALGETI	1964	38.00	1.2	0.23	X		X		

KHRAMI	KVEMO KARTLI	TSALKA	KHRAMI	KURA	QTSIA	1947	33.20	313	33.7	X		X	X	
MTIS-DZIRI	KVEMO KARTLI	DMANISI	MAMUTI-DERE	KURA	QTSIA	1981	11.00	3.3	0.82	X		X		
PANTIANI	KVEMO KARTLI	DMANISI	MASHAVERA	KURA	QTSIA	1978	10.00	5.3	0.62	X				
DMANISI	KVEMO KARTLI	DMANISI	DMANISI	KURA	DMANISI	1981		11	2	X		X		
SIONI	MTSKHETA MTIANETI	TIANETI	IORI	KURA	IORI	1963	84.80	325	10.4	X		X	X	
TBLISI SEA-SAMGORI	TBILISI	TBILISI	IORI	KURA	IORI	1956	15.00	308	11.8	X	X			X
CHALA	KAKHETI	KVARELI	CHAGURGULA	KURA	IORI	1968	4.00	1.7	0.35	X		X		
LAPIANI	KAKHETI	KVARELI	DURUJI	KURA	IORI	1971		3.5	3	X		X		
OKTOMBERI	KAKHETI	KVARELI	PSHAVIS-KHEVI	KURA	IORI	1976		1. 7	0.23	X		X		
TELET-TSKALI	KVEMO KARTLI	TETRITSKARO	IORI	KURA	IORI	1980	37.00	1. 6	0.14	X		X		
KRANCHISKHEVI	KVEMO KARTLI	TETRITSKARO	IORI	KURA	IORI	1982	14.50	1.9	0.27	X		X		
KUSHISKHEVI	KVEMO KARTLI	TETRITSKARO	KUSHIS KHEVI, IORI	KURA	IORI	1976	18.00	5	0.6	X		X		
TAVTSKARO	KVEMO KARTLI	TETRITSKARO	IORI	KURA	IORI	1986		1. 3	0.26	X		X		
NAREKVAVI	MCKHETA MTIANETI	DUSHETI	NAREKVAVI	KURA	ARAGVI	1977	41.00	6. 8	0.5	X		X		
ARKHSASHENI	KAKHETI	SAGAREJO	IORI	KURA	IORI	1994	35.00	7.3	1.1	X		X		
DEVIS-TSKALI	KAKHETI	SAGAREJO	DEVISTSKALI	KURA	DEVISTSKALI	1985	320.00	3.7	0.43	X		X		
UDABNO	KAKHETI	SAGAREJO	KURA	KURA	KURA		10.00	0.3	0.06	X		X		
CHEREMI	KAKHETI	GURJAANI	PATARA VETE, CHEREMIS KHEVI	KURA	CHEREMIS KHEVI		30.56	1.2	0.13	X		X		
LAKBE	KAKHETI		IORI, LAKBE	KURA	IORI	1989	712.00	1.27	0.168	X		X		
TELA-TSKALI	KAKHETI	DEDOPLISTSKARO	IORI	KURA	IORI	1978	37.50	1.3	0.13	X		X		
DALIS MTA (Chachuna)	KAKHETI	DEDOPLISTSKARO	IORI	KURA	IORI		38.00	180	150	X		X		
VAKE	KAKHETI	SIGNAGI	IORI, KHEVI	KURA	IORI		36.70	1.23	1.165	X		X		
ASURETIS KHEVI	KAKHETI	TETRITSKARO	ASURETIS KHEVI	KURA	ALGETI	1977	35.50	1.25	0.148	X		X		
LIPI	KAKHETI	TETRITSKARO	LIPA	KURA	LIPA		20.95	1. 95	0.264	X		X		
JANDARA	KVEMO KARTLI	GARDABANI	KURA	KURA	KURA	1978	LAKE	52 000	12.5	X				X
KUMISI	KVEMO KARTLI	GARDABANI	KURA	KURA	KURA	1964	LAKE	11 000	0.65	X				X

2.3 Meteorological observation network

The regular meteorological observations in Georgia started in the 19th century, and by the year 1900 the number of meteorological stations had reached 48. Tbilisi meteorological station was established in the year 1837, Gori in 1847, Batumi in 1881, and Poti Port in 1894. By the year 1925 about 90 meteorological stations were functioning and before the World War II their number reached 200. Some meteorological stations are located in high mountain areas with difficult access. Among them the Mamisoni Pass (established year 1932) in western Georgia and Kazbegi (established year 1933) in eastern Georgia are the oldest high altitude meteorological stations in Europe.

From the year 1966 until 1992 the observed meteorological data were sent to the (presently World) Data Centre for Meteorology in Obninsk, Russia for quality control. Since 1992 data from meteorological stations have been processed and quality controlled in Georgia. Meteorological data from all stations since their establishment are archived by NEA. Monthly and annual climatological and agrometeorological reference books are also issued and archived. Presently the meteorological and climatological data since 1966 are available in the database system CLIDATA at NEA.

The meteorological and hydrological activity is usually built on historical data and long-term data series. The history of hydro-meteorological activities in Georgia is listed in Table 2.8.

Table 2.8. Main historical hydro-meteorological activities

Year	Information
1832	Starting of episodic meteorological observations
1844	Magnetic meteorological observatory was established, regular meteorological observations started
1850	Starting of glaciological observations (Devdoraki glacier)
1883	Specialized agrometeorological observations started
1904	Actinometrical observations started
1905	Hydrological observations started
1914	The weather service was established
1930	Hydro-meteorological Service was established
1931	Air meteorological observations started
1932	Snow height field work measurements started
1937	Upper air sounding started
1964	Marine hydro meteorological observations started
1967	Works on hail active influence were started
1979	Works on precipitation artificial stimulation were started
1988	Works on avalanches artificial descending were started

In frame of the project ‘Institutional Cooperation between MOE and NEA of Georgia, and NVE’ running for the period 2013-2016, precipitation and temperature data of 203 meteorological stations were digitized, see Table 2.9 Historical meteorological stations.

Table 2.9. Historical meteorological stations

Station no.	Name	Elevation	Latitude	Longitude	NVE no.
418428	Abastumani	1265	41°45'	42°50'	3001
421445	Akhalgori	760	42°07'	44°29'	3002
420452	Akhmeta	545	42°02'	45°13'	3003
425432	Ambrolauri	544	42°31'	43°09'	3004
419420	Anaseuli	158	41°55'	41°59'	3005
417430	Akhaltsikhe	989	41°39'	43°00'	3006
414435	Akhalqalaqi	1716	41°25'	43°29'	3007
429411	Babushera	6	42°52'	41°08'	3008
419423	Bakhmaro	1926	41°51'	42°19'	3009
417435	Bakuriani	1665	41°44'	43°31'	3010
425449	Barisakho	1291	42°28'	44°56'	3011
418416	Batumi_airport	11	41°38'	41°36'	3012
417416	Batumi_hmo	2	41°39'	41°38'	3013
432404	Bichvinta	4	43°09'	40°21'	3014
415446	Bolnisi	534	41°27'	44°33'	3015
418434	Borjomi	790	41°50'	43°24'	3016
417418	Chaqva	30	41°44'	41°44'	3017
420423	Chokhatauri	144	42°01'	42°15'	3018
415461	Dedoplistskaro	800	41°28'	46°05'	3019
413442	Dmanisi	1309	41°20'	44°12'	3020
421447	Dusheti	922	42°05'	44°42'	3021
433403	Gagra	7	43°16'	40°17'	3022
434403	Gagra_ridge	1644	43°21'	40°17'	3023
426417	Gali	50	42°38'	41°44'	3024
415451	Gardabani	300	41°27'	45°06'	3025
416425	Goderdzi_pass	2030	41°38'	42°31'	3026
420441	Gori	609	42°00'	44°06'	3027
431406	Gudauta	46	43°06'	40°38'	3028
418458	Gurjaani	410	41°45'	45°46'	3029
425446	Jvari_pass	2395	42°30'	44°27'	3030
427445	Kazbegi_hm	3653	42°41'	44°32'	3031
429422	Khaishi	730	42°57'	42°11'	3032
420436	Khashuri	690	42°00''	43°37'	3033
416423	Khulo	946	41°39'	42°19'	3034
417447	Kojori	1381	41°40'	44°42'	3035
419458	Kvareli	449	41°58'	45°50'	3036
429417	Kvezani	268	42°51'	41°41'	3037
418463	Lagodekhi	429	41°49'	46°18'	3038
421420	Lanchkhuti	10	42°06'	42°02'	3039
430415	Lata	299	43°02'	41°29'	3040
427425	Lebarde	1491	42°44'	42°29'	3041
428427	Lentekhi	731	42°47'	42°44'	3042

427438	Mamisoni_pass	2854	42°42'	43°47'	3043
417444	Manglisi	1194	41°42'	44°23'	3044
424424	Martvili	176	42°25'	42°23'	3045
431428	Mestia	1441	43°03'	42°45'	3046
420435	Mta-sabueti	1242	42°02'	43°29'	3047
419446	Mukhrani	550	41°56'	44°35'	3048
427415	Ochamchire	4	42°42'	41°28'	3049
424457	Omalo	1870	42°23'	45°39'	3050
426434	Oni	789	42°35'	43°27'	3051
415439	Paravani	2100	41°28'	43°52'	3052
424447	Pasanauri	1070	42°21'	44°42'	3053
421416	Poti	1	42°08'	41°42'	3054
434408	Pskhu	685	43°24'	40°49'	3055
416419	Qeda	256	41°36'	41°57'	3056
418418	Qobuleti	7	41°50'	41°47'	3057
422426	Qutaisi	113	42°14'	42°39'	3058
424434	Sachkhere	455	42°21'	43°25'	3059
417453	Sagarejo	802	41°44'	45°20'	3060
422424	Samtredia	28	42°10'	42°25'	3061
423421	Senaki	34	42°16'	42°04'	3062
414463	Shiraqi	555	41°24'	46°20'	3063
427437	Shovi	1509	42°42'	43°41'	3064
416459	Sighnaghi	795	41°37'	45°55'	3065
430410	Sokhumi	116	43°01'	41°00'	3066
427447	Stefancminda	1809	42°40'	44°39'	3067
417450	Tbilisi_airport	462	41°41'	44°57'	3068
418448	Tbilisi_hmo	427	41°45'	44°46'	3069
419455	Telavi	568	41°56'	45°29'	3070
416445	Tetri_tskaro	1151	41°33'	44°28'	3071
421449	Tianeti	1099	42°07'	44°58'	3072
424429	Tkibuli	593	42°21'	42°59'	3073
424418	Torsa	10	42°21'	41°48'	3074
427428	Tsageri	474	42°38'	42°46'	3075
416441	Tsalka	1458	41°36'	44°05'	3076
420434	Tsipa	673	42°00'	43°26'	3077
422439	Tskhinvali	862	42°14'	43°59'	3078
417434	Tskhratskaro	2466	41°41'	43°31'	3079
416460	Tsnori	223	41°38'	46°01'	3080
415454	Udabno	750	41°30'	45°28'	3081
417449	Varketili	549	41°43'	44°53'	3082
418429	Zekari_pass	2180	41°50'	42°52'	3083
421430	Zestaphoni	148	42°08'	43°01'	3084
425419	Zugdidi	118	42°31'	41°53'	3085
43034100	Achadara	48	43°03'00''	041°00'00''	3086

41414242	Adigeni	1151	41°41'00''	042°42'00''	3087
42034350	Agara	638	42°03'00''	043°50'00''	3088
42334252	Alpana	366	42°33'40''	042°50'58''	3089
42244134	Anaklia	3	42°24'00''	041°34'00''	3090
41194346	Aragiali	1900	41°19'00''	043°46'00''	3091
41294330	Arakva	1650	41°29'00''	043°30'00''	3092
41394250	Arali	1010	41°39'00''	042°50'00''	3093
42074533	Artana	480	42°07'00''	045°33'00''	3094
41554406	Ateni	716	41°55'00''	044°06'00''	3095
41444310	Atskuri	970	41°44'00''	043°10'00''	3096
42024440	Bazaleti	870	42°02'00''	044°40'00''	3097
43024236	Becho	1270	43°02'00''	042°36'00''	3098
42134519	Birkiani	758	42°13'00''	045°19'00''	3099
41414150	Chaqvistavi	315	41°41'00''	041°50'00''	3100
43064141	Chkhalta	710	43°06'00''	041°41'00''	3101
41454148	Dagva	200	41°45'00''	041°48'00''	3102
42264140	Darcheli	15	42°26'00''	041°40'00''	3103
41404221	Didatchara	940	41°40'00''	042°21'00''	3104
41224422	Didi Dmanisi	880	41°22'00''	044°22'00''	3105
42464330	Ghebi	1380	42°46'00''	043°30'00''	3106
41544206	Gomi	295	41°54'00''	042°06'00''	3107
41574417	Grakali	555	41°57'00''	044°17'00''	3108
42094412	Gromi	800	42°09'00''	044°12'00''	3109
43074151	Gvandra	850	43°07'00''	041°51'00''	3110
41304448	Imiri	345	41°30'00''	044°48'00''	3111
43194025	Jirkhva	71	43°19'00''	040°25'00''	3112
41154317	Kartsakhi	1863	41°15'00''	043°17'00''	3113
41554426	Kaspi	598	41°55'00''	044°26'00''	3114
41394541	Katchreti	600	41°39'00''	045°41'00''	3115
42204356	Kekhvi	895	42°20'00''	043°56'00''	3116
42014313	Kharagauli	280	42°01'00''	043°13'00''	3117
41294317	Khertvisi	1124	41°28'46''	043°17'06''	3118
41594214	Khidistavi	142	41°59'00''	042°14'00''	3119
42024148	Khidmaghala	10	42°02'00''	041°48'00''	3120
42334301	Khvantchkara	540	42°33'00''	043°01'00''	3121
42344431	Kobi	1962	42°34'00''	044°31'00''	3122
41484155	Kokhi	112	41°48'00''	041°55'00''	3123
42114429	Korinta	908	42°11'00''	044°29'00''	3124
41374349	Kushci	1500	41°37'00''	043°49'00''	3125
42374252	Lailashi	853	42°37'00''	042°52'00''	3126
43004211	Lakhami	800	43°00'00''	042°11'00''	3127
43044226	Lakhamula	1200	43°04'00''	042°26'00''	3128
42084525	Lechuri	543	42°08'00''	045°25'00''	3129
42374210	Legakhare	210	42°36'52''	042°10'17''	3130

42024459	Lelovani	1000	42°02'00''	044°59'00''	3131
42494258	Luji	1250	42°47'31''	042°59'53''	3132
42174453	Magaroskari	920	42°17'44''	044°52'04''	3133
41294448	Marneuli	431	41°29'00''	044°48'00''	3134
41394548	Melaani	700	41°39'00''	045°48'00''	3135
41384303	Minadze	970	41°38'00''	043°03'00''	3136
41414241	Mlashe	1166	41°41'00''	042°41'00''	3137
42264430	Mleta	1580	42°26'00''	044°30'00''	3138
41424143	Mtsvane Kontskhi	94	41°42'00''	041°43'00''	3139
42384211	Mukhuri	260	42°38'00''	042°11'00''	3140
42554300	Murkmeli	2100	42°55'00''	043°00'00''	3141
41574222	Nabeghlavi	475	41°57'00''	042°22'00''	3142
42104212	Naesakao	15	42°10'00''	042°12'00''	3143
43054223	Naki	1160	43°05'00''	042°23'00''	3144
42264159	Narazeni	154	42°26'00''	041°59'00''	3145
41554150	Natanebi	10	41°55'00''	041°50'00''	3146
41594322	Nebodziri (Moliti)	620	41°59'00''	043°22'00''	3147
42064207	Nigoiti	14	42°06'00''	042°07'00''	3148
41164336	Ninotsminda (Bogdanovka)	1950	41°16'00''	043°36'00''	3149
42224212	Noqalaqevi	80	42°21'24''	042°11'34''	3150
43054106	Odishi	220	43°05'00''	041°06'00''	3151
42384250	Orbeli	550	42°38'00''	042°50'00''	3152
41184338	Orojolari	1847	41°18'00''	043°38'00''	3153
42214249	Orpiri	300	42°21'00''	042°49'00''	3154
41354435	Partskhisi	710	41°35'00''	044°35'00''	3155
42224429	Pavliani	1320	42°22'00''	044°29'00''	3156
42344329	Pipileti	960	42°34'00''	043°29'00''	3157
41244348	Poka (Magharoskhevi)	2080	41°24'00''	043°48'00''	3158
42024354	Qareli	610	42°02'00''	043°54'00''	3159
41584205	Qveda bakhvi	200	41°58'00''	042°05'00''	3160
42264309	Qveda Tlughi	1100	42°26'00''	043°09'00''	3161
41274426	Qveshi	580	41°27'00''	044°26'00''	3162
43284032	Lake Ritsa	928	43°28'00''	040°32'00''	3163
42024541	Sabue	631	42°02'00''	045°41'00''	3164
41504449	Sadakhlo	419	41°50'00''	044°49'00''	3165
41184345	Saghamo	2008	41°18'00''	043°45'00''	3166
41214431	Samtsverisi	645	41°21'00''	044°31'00''	3167
41434510	Sartitchala	690	41°43'00''	045°10'00''	3168
41194445	Shaumiani	650	41°19'00''	044°45'00''	3169
42004543	Shilda	495	42°00'00''	045°43'00''	3170
42304325	Shqmeri	1750	42°30'00''	043°25'00''	3171
41374211	Shuakhevi	385	41°37'00''	042°11'00''	3172
41344202	Sikhalidzeebi	400	41°34'00''	042°02'00''	3173
41314143	Sindieti	70	41°31'00''	041°43'00''	3174

41594313	Skhliti	400	41°59'00''	043°13'00''	3175
42224326	Skhvitori	440	42°22'00''	043°26'00''	3176
42364439	Sno	1750	42°36'00''	044°39'00''	3177
42344318	Sori	800	42°34'00''	043°18'00''	3178
41174323	Sulda	1915	41°17'00''	043°20'00''	3179
42044148	Supsa	7	42°04'00''	041°48'00''	3180
42014334	Surami	743	42°01'00''	043°34'00''	3181
41404337	Tabatskuri	1995	41°40'00''	043°37'00''	3182
41424447	Tbilisi, Mtatsminda	766	41°42'00''	044°47'00''	3183
42174317	Tchiatura	350	42°17'00''	043°17'00''	3184
41404605	Tchiaura	202	41°40'00''	046°05'00''	3185
43034250	Tcholashi	1590	43°03'00''	042°50'00''	3186
41434410	Tejisi	1500	41°43'00''	044°10'00''	3187
42394419	Tepi	2100	42°39'00''	044°19'00''	3188
41484329	Tsaghveri	1028	41°48'00''	043°29'00''	3189
42064308	Tseva	220	42°06'00''	043°08'00''	3190
42344458	Tsinkhadu	1910	42°34'00''	044°58'00''	3191
41204505	Tsiteli khidi	275	41°20'00''	045°05'00''	3192
41424442	Tskneti	750	41°42'00''	044°42'00''	3193
42384333	Utsera	981	42°38'00''	043°33'00''	3194
41564208	Vakijvari	400	41°56'00''	042°08'00''	3195
42174406	Vanati	1020	42°17'00''	044°06'00''	3196
42284404	Vaneli	1310	42°28'00''	044°04'00''	3197
41484406	Zemo Akhalsopeli	1560	41°48'00''	044°06'00''	3198
42124157	Zemo Tchaladidi	7	42°12'18''	041°56'43''	3199
42544310	Zeskho	1690	42°54'00''	043°10'00''	3200
41584348	Zghuderi	623	41°58'00''	043°48'00''	3201
42064446	Zhinvali	727	42°08'00''	044°47'00''	3202
41544221	Zoti	1270	41°54'00''	042°21'00''	3203

2.4 Hydrological observation network

Hydrological observations started in Georgia in the year 1905. During the 20th century, more than 450 hydrological stations were used for observations in rivers, reservoirs and lakes. From the establishment of the hydrological station network until the year 1985 hydrological data were sent to the National Data Centre in Obninsk, Russia. Hydrological forecasts for Georgia are issued by NEA using the hydrological stations listed in Table 2.10.

The maximum number of operational hydrological stations was reached in the year 1951 with 151 stations, and until 1990 the number of operational hydrological stations were 149. See map of closed hydrological stations in Figure 2.2 and list of historical hydrological stations in Table 2.11.

In 2012 NEA implemented the database system WinZPV from the Czech Hydrological Institute to record river water measurements and various additional information used to characterize the river network system. In frame of the project 'Institutional Cooperation between MOE and NEA of Georgia, and NVE' running for the period 2013-2016 all historical hydrological data (Water Level, Discharge) were digitized and are now available in the database system WinZPV, as well as the Aquarius database system from Aquatics Informatics, one of the most powerful platforms available for managing water resources. With the Aquarius database system environmental data from multiple sources are securely stored for fast, central access. Water managers can easily correct and quality control data, build rating curves, derive statistics, and report in real-time to meet stakeholder expectations for timely, accurate water information.

Table 2.10. Hydrological stations used for preparation of hydrological forecasts

No.	River name	Hydrological station name	Catchment area [km^2]	In operation since	Latitude	Longitude	Historical discharge m^3/s	
							Max	Min
1	Acharistskali	Qeda HM	1360	1937	41^0 35'	41^0 55'	770	4.00
2	Chorokhi	Mirveti	20900	1969	41^0 31'	41^0 43'	1460	40.50
3	Enguri	Khasishi	2780	1937	42^0 56'	42^0 10'	1190	8.50
4	Khobi (Khobistskali)	Legakhare	310	1942	42^0 36'	42^0 10'	536	1.50
5	Rioni	Alpana	2830	1919	42^0 33'	42^0 50'	1470	10.80
6	Kvirila	Sahckhere	533	1925	42^0 20'	43^0 24'	381	1.20
7	Tskhenistskali	Luji	506	1932	42^0 47'	42^0 59'	188	2.60
8	Tekhuri	Naqalaqevi	558	1931	42^0 21'	42^0 11'	1526	2.60
9	Rioni	Chaladidi	13300	1928	42^0 12'	41^0 56'	4860	120.0
10	Supsa	Chokhatauri	316	1932	42^0 00'	42^0 14'	290	0.40
11	Faravani	Khertvisi	2350	1936	41^0 28'	43^0 17'	437	5.30
12	Mtkvari (Kura)	Khertvisi	4980	1927	41^0 28'	43^0 17'	742	5.50
13	Mtkvari (Kura)	Likani	10500	1933	41^0 49'	43^0 21'	1520	17.5
14	Gudamakris Aragvi	Mouth with rv. Shavi Aragvi	235	1939	42^0 20'	44^0 41'	156	0.70
15	Mtiuletis Aragvi (White Aragvi)	Pasanauri	335	1958	42^0 20'	44^0 41'	166	3.00
16	Fshavis Aragvi	Magaroskari	736	1958	42^0 17'	44^0 52'	338	3.50
17	Mtkvari (Kura)	Tbilisi	21100	1914	41^0 43'	44^0 47'	2450	12.0
18	Mashavera	Kazreti	690	1977	41^0 23'	44^0 25'		
19	Alazani	Shaqriani	2190		41^0 59'	45^0 34'	1160	8.00

No-Operating Hydrological Stations

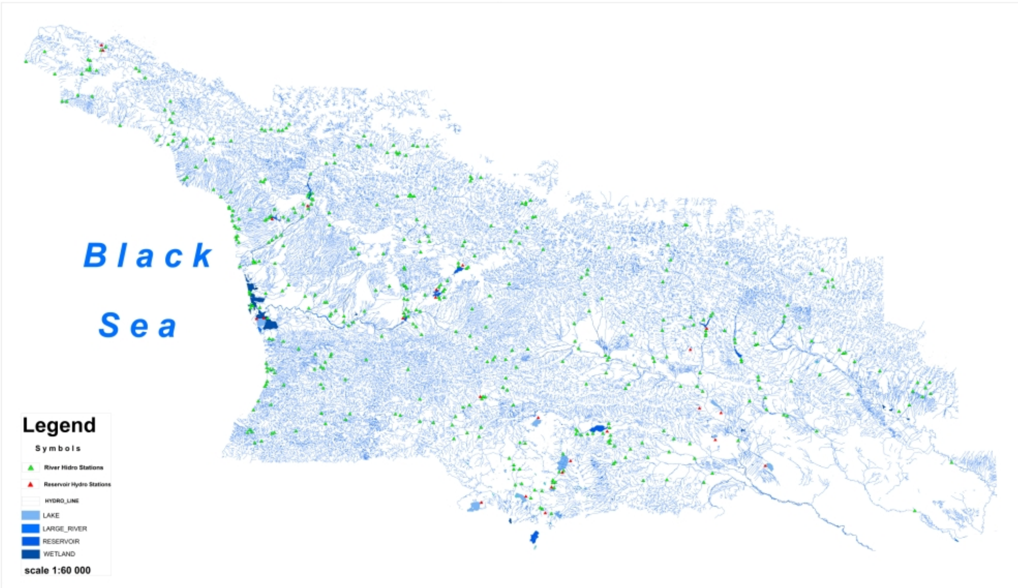

Figure 2.2. Closed hydrological stations

Table 2.11. Historical hydrological stations

No.	River name	Hydrological station name	Area km²	Latitute	Longitude	Water level and discharge period
1	Psou	V. Leselidze	420	43 24	40 00	1929-37
2	NakaduliN	V. Baghnari	25.0	43 27	40 49	1946-49
3	Zhvaviakvara (Zhoekvara)	C. Gagra	72.0			1961
4	Bzipi	Up to r. Reshevie	337	43 20	40 51	1934-41, 60-76
5	Bzipi	V. Qvemo-Bitaga	507	43 22	40 50	1976-91
6	Bzipi	After r. Baviu	632	43 23	40 48	1960-62
7	Bzipi	Up to r. Gega	899	43 22	40 28	1930-32, 36-39
8	Bzipi	0.8 km up to r. Gega	901			1960-62
9	Bzipi	1.2 km After r. Gega	1320			1961, 62
10	Bzipi	V. Jirkhva	1410	43 19	40 25	1917, 32-42, 44-91
11	Bzipi	V. Kaldakhavra	1460	43 15	40 24	1914-17, 26-34
12	Bzipi	V. Akhaladzi	1510			1961, 62
13	Bzipi	Brige of Bichvinta	1510	43 12	40 16	1934, 71-91
14	Gega	6.2 km up to r. Iupshara	153	43 25	40 28	1930-34, 60, 61, 63-70
15	Gega	0.5 km to the mouth	421	43 22	40 28	1930-32, 34, 35, 37-42,44-70
16	Lashipse	At the mouth	115	43 38	40 32	1980-91
17	Iupshara	At Lake Ritsa	170			1960, 61
18	Iupshara	At the mouth	226			1932, 34
19	Mchishta	Trout fishery	21.8	43 13	40 30	1961-91
20	Aapsta	C. Gudauta	243			1935

21	Gumista	V. Aachadara	556	43 03	41 00	1926-36, 38, 39, 41, 42, 52-91
22	Gumista	V. Gumista	579	43 01	40 57	1942-49, 51
23	West Gumista	After Sokhumi HPP	114	43 09	41 01	1935-41, 44-48
24	East Gumista	Up to Sokhumi HPP	315	43 10	41 03	1932-48, 52-91
25	E. Gumista	V. Derekei	172	43 08	41 03	1930-41
26	Cumuri	At the mouth	42.0	43 10	41 03	1932-48
27	Derekei	V. Derekei	38.3	43 07	41 04	1946-48, 50, 52-55
28	Besleti	V. Qvemo-Linda	63.0	43 03	41 05	1930-32
29	Besleti	V. Abzhakva	83.0	43 01	41 01	1986-91
30	Besleti	C. Sokhumi	87.5	43 01	41 00	
31	Kelasuri	V. Aleqsandrovka	192	43 03	41 10	1930-34
32	Kelasuri	V. Baghmarani	214	42 56	41 06	1973-91
33	Machara	V. Merkheuli	88.0	42 59	41 09	1940-47, 49-58
34	Patara-Kodori	V. Noushi	5.70	42 57	41 16	1946-49, 51-53
35	Kodori	V. Gentsvishi	436	43 06	41 49	1944-48
36	Kodori	V. Azhara	480			
37	Kodori	V. Lata	1420	43 02	41 31	1931-91
38	Kodori	Up to r. Amtkeli	1520			
39	Kodori	V. Ganakhleba	1990	42 58	41 18	1934-62
40	Kodori	V. Varcha	2020	42 51	41 11	1965-90
41	Kodori	V. Adziubzha	2020	43 07	41 50	1926-35
42	Gvandra	V. Gvandra	197	43 06 29.93	41 49 52.82	1961-39, 44-51, 53-90
43	Klichi	V. Omarishara	84.7	43 15	41 54	1962-76
44	Sakeni	V. Gvandra	225	43 12	42 07	1930-34, 36-39
45	Mramba	V. Mramba	172	43 03	41 50	1931, 33, 34
46	Chkhalta	V. Chkhalta	465	43 21	41 23	1930-90
47	Amtkeli	V. Amtkeli	215	43 16	41 21	1932-34
48	Jampali	V. Amtkeli	380	43 12	41 25	1930-34, 36-42, 44, 46-48, 50-53, 55-58
49	Dghamishi	V. Tamishi	118	42 59	41 23	1930-34
50	Mokvi	V. Aradu	324	42 46	41 28	1930-34
51	Mokvi	At the mouth		42 46	41 26	1986-91
52	Ghalidzga	V. Khukhuna	237	42 51	41 43	1939-45, 47-61
53	Ghalidzga	C. Tkvarcheli	242	42 51	41 42	1961-91
54	Ghalidzga	V. Kvezani	243	42 50	41 43	1934, 35, 37, 38
55	Ghalidzga	C. Ochamchire	369	42 34	41 30	1926-34
56	Anaria	V. Ilori	29.0			1933, 34
57	Anaria	At the mouth	103	42 42	41 29	1932-34
58	Jakoba (Chaoba)	V. Jakoba	24.0	42 39	41 30	1928-34
59	Okumi	V. Achigvara	245	42 42	41 38	1926-30, 32-35, 37, 39, 40, 79-85

60	Okumi	V. Gudava	258	42 39	41 33	1930-35, 43, 46-51, 53-64
61	Okumi	At the mouth	558	42 32	41 34	1928-30, 33, 34, 80-85
62	Eristskali (Didi-Eristskali)	V. Lekukhona	12.0	42 42 02	41 56 12	1959-61
63	Eristskali (Didi-Eristskali)	Bupass canal Enguri HPP	87.0	42 39	41 53	
64	Eristskali (Didi-Eristskali)	After r. Cheghali	122			1969-74, 76-78
65	Eristskali (Didi-Eristskali)	V. Rechkhochkhiri	163	42 39	41 48	1956-62
66	Eristskali (Didi-Eristskali)	HPP, Channel	163	42 39	41 48	
67	Eristskali (Didi-Eristskali)	C. Gali	200	42 39	41 43	1932
68	Eristskali(Didi-Eristskali)	V. Gudava	295	42 37	41 31	1928-34
69	Galkhumlia	V. Fartonokhori	2.30			1959-61
70	Rechxi	V. Ghumurishi	25.0	42 41	41 49	1974-87
71	Rechxi	V. Rechkhi	42.6	42 39	41 49	1941-43, 47-58
72	Patara-Eristskali	V. Gudava	19.0	42 36	41 31	
73	Patara-Eristskali	At the mouth	20.0			
74	Gagida	V. Arazati	130	42 34	41 33	1929-33
75	Gagida	V. Gagida	145	42 32	41 32	1931-33
76	Ojoghore	V. Arazati	74.0	42 35	41 32	1929-33
77	Okvinore	V. Gagida	39.0	42 32	41 33	1932-34
78	Enguri	V. Ipari	362	43 01	42 50	1967-91
79	Enguri	V. Latali	975	43 00	42 38	1933, 34, 55-62
80	Enguri	V. Sgimeri	980	43 00	42 38	1935-38
81	Enguri	V. Qartvani	1270	41 01	42 33	
82	Enguri	V. Lakhamula	1410	43 03	42 27	1931-42
83	Enguri	V. Dizi	1760	43 02	42 21	1932-42, 56-80
84	Enguri	V. Khaishi (Tkheishi)	2780	42 56 42.73	42 1042.13	1937-43, 45-47, 49-52, 54, 1956-2011
85	Enguri	V. Skormeti	2800	42 56	42 09	1931-37
86	Enguri	V. Khuberi	2970	42 52	42 02	1931, 32, 55-78
87	Enguri	V. Khudoni	3130	42 53	41 42	1946-49
88	Enguri	V. Purashi	3160	42 47	42 02	1932-47
89	Enguri	Dam, downstream	3170	42 46	42 02	1976-80
90	Enguri	C. Jvari	3170	42 43	42 02	1917-20, 28-31, 34-45, 50-62
91	Enguri	V. Rukhi	3460	42 34	41 57	
92	Enguri	V. Chuburkhinji	3470	42 34	41 51	1926-31
93	Enguri	V. Abastumani	3520	42 31	41 48	
94	Enguri	V. Shamgona	3530	42 32	41 47	1930-34
95	Enguri	V. Darcheli	3640	42 26	41 40	1936-43, 45-62, 76-91
96	Enguri	V. Anaklia	4040	42 24	41 34	1963-75
97	Mulkhra	V. Cholashi	186	43 03	42 50	1931, 32
98	Mulkhra	Mineral w. spring	197	43 02	42 44	1962-87
99	Mulkhra	V. Latali	435	43 01	42 38	1932-38

100	Mestiachala	D. Mestia	144	43 03	42 44	1931, 32, 39, 40, 42, 43, 46-90
101	Dolra	V. Becho	146	43 02	42 35	1930-33, 56-62
102	Nakra	V. Naki (Nakra)	126	43 05	42 23	1931, 32, 37-43, 45, 46, 48-91
103	Khumpreri	At the mouth	160	43 01	42 24	1931, 32, 56-62
104	Nenskra	V. Lakhami	468	43 01	42 12	1930-43, 55-80
105	Tkheishi	V. Khaishi	222	42 56	42 12	1931, 32, 50-76
106	Legvechara	V. Purashi	0.30			1958-61
107	Magana	at the Dam Enguri HPP	131			1956, 57
108	Magana	At the mouth	139	42 44	42 02	1956-80
109	Olori	V. Muzhava	36.8			1959-61
110	Olori	At the mouth	69.7	42 40	41 59	1962-80
111	Jumi	V. Caishi	174	42 26	41 54	1933-35, 78-87
112	Jumi	V. Darcheli (Kirovi)	368	42 25	41 40	1930, 31, 69-91
113	Jumi	V. Kirovi	368	42 26	41 41	1956-60
114	Jumi	At the mouth	338	42 25	41 40	1931-35
115	Chkhouchi	C. Zugdidi	60.0	42 31	41 53	1945-55, 85-91
116	Khobi (Khobistskali)	V. Mukhuri	216	42 38	42 11	1935
117	Khobi (Khobistskali)	V. Legakhare	310	42° 36	42° 10	1942, 1947-2011
118	Khobi (Khobistskali)	C. Khobi	1030	42 19	41 55	1927-35, 79-92
119	Khobi (Khobistskali)	V. Khorga	1060	42 16	41 49	1928-34
120	Khobi (Khobistskali)	V. Qariata	1070	42 16	41 45	1929-34
121	Khobi (Khobistskali)	V. Kulevi	1340	42 09	41 02	1927-34, 73-86
122	Chanistskali	V. Squri	57.8	42 42	42 10	1947-56
123	Civa	Above v. Kulevi				
124	Civa	V. Kulevi	185	42 16	41 38	1927-34, 80-90
125	Rioni	V. Ghebi	222	42 46	43 31	1934, 35, 50-55
126	Rioni	V. Glola	629	42 42	43 35	1925, 26 33-58
127	Rioni	V. Utsera	707	42 38	43 33	1958-87
128	Rioni	C. Oni	1060	42° 34	43° 25	1935-38, 40-93
129	Rioni	V. Khidikari (Tsesi)	2010	42° 32	43°11	1925, 26, 29-47, 50-87
130	Rioni	V. Chrebalo		42 33	42 58	
131	Rioni	V. Alpana	2830	42° 33	42° 50	1919-22, 1926-2011
132	Rioni	V. Namokhvani	3450	42 24	42 42	1933-41, 53-98
133	Rioni	Gumati HPP	3510	42 16	42 42	1962-2005
134	Rioni	Up to the Dam Rioni HPP	3510	42 20	42 42	1933-52, 55-58
135	Rioni	Rioni HPP	3510	42 12	42 42	1996-2000, 05
136	Rioni	C. Qutaisi	3540	42 16	42 42	1910-34
137	Rioni	St. Rioni	3560	42 12	42 42	1913-15
138	Rioni	Varcikhe HPP	8100	42 43	42 08	1978-2005
139	Rioni	C. Samtredia	9440	42 08	42 20	1937

140	Rioni	V. Dapnari	9440	42 19	42 07	1987-94
141	Rioni	V. Chaladidi (Saqochakidze)	13300	42° 12	41° 56	1928-2011
142	Rioni	V. Patara-Poti	13400	42 11	41 47	1930-34, 59, 60
143	Rioni	C. Poti (Bridge if station)	13400	42 09	41 41	1926-35, 36, 37
144	Rioni (North Branch)	C. Poti	13400	42 10	41 39	1971-85, 88-98
145	Rioni (South Branch)	C. Poti	13400	42 09	41 40	1971-94
146	Chveshura	C. Ghebi	74.8	42 47	43 33	1934, 35
147	Chveshura	C. Ghebi (0.5 km to the mouth)	100	42 46	43 32	1934, 35
148	Khvargula	Brige	17.6			1934-36
149	Chanchakhi	At the mouth	183	42 42	43 38	1950-55, 67-94
150	Sakaura	V. Lagvanta	168	42 37	43 28	1936, 38-58
151	Jejora	V. Sheubani	217			1933-35
152	Jejora	V. Somitso	418	42 37	43 28	1932-38
153	Jejora	V. Pipileti	408	42 34	43 29	1947-94
154	Jejora	C. Oni	434	42 34	43 28	1933, 34, 39, 41-43, 46
155	Kheori	V. Bokva	47.2	42 32	43 24	1945-53
156	lukhuni	V. Uravi	175			
157	Veleula	After r. Dolabistavi	20.4			1951-54
158	Riceula	V. Tsesuri	125	42 35	43 08	1926, 1930-35
159	Riceula	V. Kldisubani	157	42 33	43 07	1973-78
160	Shaora	V. Qveda-Tlughi	29.4	42 26	43 09	1956-89
161	Shaora	V. Kherga	126	42 28	43 07	1945-53
162	Shaora	Shaori HPP				1991-2005
163	Sharaula	V. Udabno	8.10	41 30	45 23	1946-62
164	Lajanura	V. Orbeli	231	42 38	42 50	1959-99
165	Lajanura	V. Surmushi	282	42 35	42 51	1951-59
166	Lajanura	V. Alpana	287	42 34	42 52	1926, 27, 30, 31, 34, 35, 38-58
167	Ghvirishi	At the mouth	24.1			1950, 51
168	Lekereti	At the mouth	26.6			1955-57
169	Sakalmakhe	V. namoxvani	19.5	42 25	42 42	1934-37
170	Kvirila	C. Sachkhere	533	42° 20	43° 24	1925, 26, 32-35, 37-39, 67-2011
171	Kvirila	C. Chiatura	883	42 17	43 18	1917-20, 40-45, 47-52, 54-62
172	Kvirila	V. Rkvia	1050	42 13	43 11	1936-40
173	Kvirila	st. Shorapani	1110	42 06	43 05	1915-18, 22-28, 30-37
174	Kvirila	C. Zestaponi	2490	42° 06	43° 02	1930-2010
175	Kvirila	V. Sviri		42° 07' 10.08"	42° 58'	
176	Kvirila	V. Nakhshirghele	3230	42 12	42 50	1950-58
177	Kvirila	V. Ajameti	3270	42 12	42 47	1912-18, 20, 34, 72-78
178	Kvirila	At the mouth	3620	42 11	42 44	1928-32, 33-35

179	Chikhura	V. Skhvitori	79.0	42 22	43 26	1941-77
180	Dzirula	V. Tseva	1190	42 05	43 07	1932-97
181	Dumala	V. Boriti	117	42 08	43 17	1937, 38
182	Chkherimela	V. Tsipa	17.2	42 01	43 28	
183	Chkherimela	V. Babi	147	41 59	43 20	1932-69
184	Chkherimela	V. Qvebi	149	41 59	43 20	1970-87
185	Chkherimela	D. Kharagauli	398	42 01	43 13	1932, 33, 40-51, 53-97
186	Chkherimela	V. Dzirula	484	42 05	43 10	1932-35
187	Zvare	V. Zvare	30.5	41 58	43 24	1946-56
188	Bzholiskhevi	V. Marelisi	118	41 59	43 18	1947-62
189	Tkibula	C. Tkibuli	31.5	42 20	43 00	1938, 39, 41-98
190	Tkibula	V. Bziauri	43.9	42 19	42 58	1949-56
191	Tkibula	V. Akhalsopeli	49.4	42 18	42 58	1945-56
192	Tkibula	Tkibuli HPP	91.8	42 16	42 57	1972-92
193	Tkibula	V. Dzevri	126	42 15	42 57	1949-55
194	Skipi	V. Satsire	6.00	42 20	42 57	1956-62
195	Skipi	At the mouth	35.7	42 17	42 56	1945-56
196	Qveruna	V. Gogni	9.80	42 17	42 59	1949-56
197	Sabataghele	V. Cuckhvati	16.0	42 16	42 51	1945-53
198	Tskaltsitela	P. Sapichkhia	179	42 18	42 46	1925-29
199	Tskaltsitela	V. Kvakhchiri	221	42 12	42 44	1950-52, 54-58, 72-80
200	Tskaltsitela	St. Rioni	226	42 12	42 43	1928-35, 38-40
201	Khanistskali	C. Baghdati	655	42 03	42 50	1930, 31, 34-97
202	Khanistskali	V. Rokiti	898	42 07	42 07	1972-78
203	Khanistskali	V. Didvela	907	42 08	42 47	1950-58
204	Khanistskali	V. Varcikhe	907	42 08 57.02	42 43 42.04	
205	Tsablarastskali	V. Sairme	102	41 54	42 45	1964-93
206	Sulori	V. Salkhino	154	42 05	42 31	1926-35, 70-87
207	Gubistskali	V. Gubistskali	307	42 04	42 27	1930-34
208	Gubistskali	V. Ianeti	426			1954-56
209	Tskaltubo	C. Tskaltubo	23.8	42 19	42 36	1936-40
210	Ckhenistskali	V. Luji	506	42°47	42° 59	1932-43, 47-51, 53-2011
211	Ckhenistskali	V. Leqsuri	760	42 47	42 44	1932-35, 41
212	Ckhenistskali	D. Lentexi	1200	42 47	42 44	1955-65
213	Ckhenistskali	V. Rckhmeluri (Naghomari)	1450	42 39	42 47	1935-37, 39-41, 49-53, 58-93
214	Ckhenistskali	V. Zubi	1700	42 33	42 40	1949-60
215	Ckhenistskali	V. Khidi (Bambuaskhidi)	1950	42° 25	42° 29	1917, 24-37, 39-46, 48-96
216	Ckhenistskali	C. Samtredia	2110	42 09	42 18	1915-35

217	Ckhenistskali	V. Gautskinari	2120	42 08	42 18	1932-34, 38-42, 55-58, 79-86
218	Zeskho	V. Zeskho	44.8	42 54	43 11	1961-94
219	Koruldashi	Cana HPP, construction site	18.0			1938-40
220	Koruldashi	V. Cana	44.4	42 53	43 09	1935-40
221	Nesharistskali	At the mouth	20.4			1938-40
222	Leusheristskali	V. Leusheri	9.37	42 51	42 54	1946-50, 52
223	Laskadura	D. Lentekhi	127	42 48	42 43	1932-38
224	Kheledula	V. Kheledi	296			1967, 68
225	Kheledula	V. Leqsuri	313	42 48	42 44	1933-38
226	Okace (Satsisqvilo)	V. Kinchkha (Gordi)	64.0	42 30	42 34	1949-51, 53-76
227	Noghela	C. Abasha (2.5 km to c. Samtredia)	85.0	42 12	42 14	1915-20, 24-34
228	Noghela	V. Naesakao (4.7 km to the mouth)	125	42 10	42 13	1931-34
229	Noghela	V. Naesakao (2.5 km to the mouth)	130	42 10	42 12	1956-58, 81-87
230	Texuri	V. Salkhino	324	42 29	42 21	1933-35, 37-39, 48-53
231	Texuri	V. Naqalaqevi	558	42° 21	42° 11	1931, 32, 37-42, 44-92, 94-2011
232	Texuri	C. Senaki		42 16	42 06	1915-21, 28--34
233	Texuri	Farm of Tekhuri	1040	42 12	42 08	1956, 57
234	Lebarde	V. Lebarde	7.80	42 44	42 29	196582
235	Tsachkhura	V. Salkhino	83.2	42 31	42 22	1931, 32, 36-40
236	Abasha	V. Gachedili	86.8	42 29	42 23	1979-87
237	Abasha	C. Abasha	319	42 14	42 10	1915-20, 24-35
238	Abasha	V. Sagvazao	329	42 13	42 10	1935, 79-92
239	Civi	C. Senaki	177	42 16	42 02	1915, 17-21, 28-35
240	Pichori	At the mouth	404	42 13	41 59	1929-35, 82
241	Supsa	V. Zemo-Surebi	186	41 58	42 27	1935, 37, 38
242	Supsa	D. Chokhatauri	316	42° 00	42° 14	1932--35, 40-48, 50-2011
243	Supsa	St. Supsa	1100	42 02	41 49	1915-17, 19-34, 37-39
244	Supsa	V. Khidmaghala	1100	42 02	41 48	1940-50, 54-92
245	Gubazeuli	V. Khidistavi	337	41 58	42 14	1928-47, 49-91
246	Kalasha	V. Khidistavi	88.6	41 58	42 14	1934, 35
247	Bakhvistskali	V. Bakhmaro	33.4	41 50	42 20	1945-47, 49-50, 52-78
248	Bakhvistskali	V. Ukanava	79.0	41 56	42 11	1938-47
249	Bakhvistskali	V. Qveda-Bakhvi	116	41 58	42 07	1931, 32, 34-47, 49-87
250	Mamatisghele	V. Silauri	2.99	41 59	42 01	1947, 49-53
251	Shuti	V. Chochkhati	12.3	42 02	41 54	1971
252	Natanebi	V. Korisbude	54.0	41 52	42 12	1943-49
253	Natanebi	V. Vakijvari	70.0	41 56	42 08	1942-49
254	Natanebi	St. Natanebi	469	41 55	41 49	1930-47, 49-91
255	Bzhuzhi	Bzhuzhi HPP, Dam	97.5	41 52	42 07	1940, 41, 50-55, 62-92

256	Bzhuzhi	After Bzhuzhi HPP	105	41 52	42 07	1956-58
257	Bzhuzhi	V. Gomi	112	41 54	42 06	1939-41, 46, 47, 49-87
258	Choloqi	St. Natanebi	55.2	41 54	41 50	1931, 34
259	Choloqi	Up to r. Ochkhamuri	83.0	41 54	41 47	1931
260	Choloqi	After r. Ochkhamuri	156	41 54	41 47	1931
261	Ochkhamuri	St. Ochkhamuri	38.9	41 53	41 19	1930, 31, 40-56
262	Shavi-Ghele	D. Ochkhamuri	6.09	41 51	41 50	1930, 31
263	Achkva	C. QobuleTi	33.8	41 49	41 48	1940-91
264	Kintrishi	V. Kokhi	191	41 48	41 54	1930-33
265	Kintrishi	C. Qobuleti	251	41 48	41 47	1930-35
266	Dekhva	C .Qobuleti	40.0	41 48	41 47	1928-35
267	Chaqviswyali	V. Khala	120	41 42	41 48	1940-87
268	Caqvistskali	C. Chaqvi	173			1926-40
269	Abanostskali	V. Makhinjauri	3.90	41 40	41 42	1946-57
270	Chorokhi	V. Maradidi	20500	41 30	41 43	1950-62
271	Chorokhi	V. Mirveti	20900	41° 31	41° 43	1969-2011
272	Chorokhi	V. Erge	22000	41 33	41 42	1930-48, 51, 52, 55-60, 63-68, 70-92
273	Chorokhi	V. Kapandidi	22000	41 34	41 41	1930-35
274	Chorokhi	Maxos-Xidi (Makho Brige)		41 34	41 39	1940-58
275	Machakhlistskali	V. Acharisaghmarti		41 31	41 47	
276	Machakhlistskali	V. Sindieti	362	41 31	41 45	1941-43, 45-93
277	Acharistskali	D. Khulo	251	41 38	42 19	1940-69, 71-93
278	Acharistskali	D. Qeda	1360	41 35	41° 55	1937-2011
279	Acharistskali	V. Makhunceti	1450	41 34	41 52	1934-42
280	Acharistskali	Achara HPP	1470	41 35	41 52	1955-92
281	Acharistskali	V. Acharistskali	1540	41 32	41 43	
282	Sacikhuri	V. Didachara	98.0	41 40	42 21	1941-92
283	Chirukhistskali	D. Shuakhevi	326	41 37	42 11	1942-92
284	Chvanistskali	V. Chvana	173			1984-87
285	Merisi (Akavreta)	V. Sikhalidzeebi (Gundauri, Ortamele)	88.2	41 34	42 01	1942-92
286	Makho	V. Makho	11.6	41 34	41 40	1940-58
287	Tergi	D. Stefantsminda	778	42 39	44 38	1936-42, 53-93
288	Narvani	V. Kobi		42 33	44 30	1947-59
289	Chkheri	D. Stefantsminda	27.3	42 40	44 39	1947-92
290	Tushetis-Alazani	V. Jvarboseli	178	42 25	45 30	1950-67
291	Tushetis-Alazani	V. Khakhabo	314	42 22	45 37	1951-77
292	Tushetis-Alazani	V. Shenaqo	873	42 24	45 40	1952-77
293	Khisos-Alazani (Chanchakhovnistskali)	V. Khiso	109	42 21	45 36	1951-73, 75-77

294	Piriqitis-Alazani	V. Dartlo	260	42 26	45 35	1950-77
295	Piriqitis-Alazani	V. Omalo	366	42 22	45 39	1951-77
296	Mtkvari (Kura)	V. Khertvisi	4980	41° 28	43° 17	1927-33, 36-2011
297	Mtkvari (Kura)	D. Aspindza	7420	41 34	43 15	1929-35
298	Mtkvari (Kura)	V. Rustavi	7650	41 37	43 07	1928-34
299	Mtkvari (Kura)	V. Minadze	8010	41 38	43 03	1933-94, 97, 98 2001-04, 2006
300	Mtkvari (Kura)	V. Tsnisi	9980	41 41	43 05	1928-34
301	Mtkvari (Kura)	V. Atskuri	10200	41 44	43 10	1928-30, 35-37
302	Mtkvari (Kura)	V. Qvabiskhevi	10400	41 46	43 15	1941, 44-48, 92
303	Mtkvari (Kura)	Up to the Chitaxevi HPP	10400	41 47	43 18	1971-90
304	Mtkvari (Kura)	Chitakhevi HPP	10400	41 47	43 18	1955-87
305	Mtkvari (Kura)	C. Borjomi	10500	41° 49	43° 21	1932-2011
306	Mtkvari (Kura)	C. Akhaldaba	11300	41 56	43 30	1932-37, 56-58
307	Mtkvari (Kura)	C. Qareli	11400			1947-53, 55-58
308	Mtkvari (Kura)	C. Gori	15500	41 59	44 06	1936-42
309	Mtkvari (Kura)	V. Grakali	16700	41 57	44 17	42-49, 53, 55-57, 62-93
310	Mtkvari (Kura)	V. Dzegvi	18000	41 51	44 37	1928-30, 33-43, 47-53, 55-57, 60-85
311	Mtkvari (Kura)	C. Mckheta	18000			
312	Mtkvari (Kura)	V. Zahesi	20800	41 49	44 46	1955-86, 87, 88, 89-92, 94-96
313	Mtkvari (Kura)	C. Tbilisi	21100	41° 43	44° 47	1862-66, 1914-16, 23-93, 1995-2011
314	Mtkvari (Kura)	C. Rustavi	21900			1944-53
315	Shashka	V. Tambovka	37,4	41 49	43 49	1958-63
316	Magharoskhevi	At the mouth	45,1	41 25	43 50	1947-55
317	Faravani	V. Poka	272	41 24	43 48	1927-34, 39-43, 45-65, 76-93
318	Faravani	V. Gandzani, above springs	356	41 21	43 45	1948-52, 54-63, 69, 70-72
319	Faravani	V. Gandzani, below springs	454	41 20	43 45	1948-63, 69-72
320	Faravani	V. Saghamo	564	41 18	43 44	1927-34, 39, 41-43, 48-63
321	Faravani	V. Araqali	584	41 19	43 46	1945, 46, 48, 51-95
322	Faravani	V. Orojalari	1010	41 18	43 38	1936, 38-46, 55-58, 60-90
323	Faravani	V. Almali	1290	41 20	43 31	1927-37, 52, 54-59
324	Faravani	V. Diliska	1640	41 26	43 29	1927-32
325	Faravani	V. Murjakheti	2140	41 28	43 27	1930-34, 49-51
326	Faravani	V. Khertvisi	2350	41° 28	43 ° 17	1936-2011
327	Gandzisxevi	V. Gandzani	72,4	41 21	43 46	1958-61
328	Bughdasheni	V. Gorelovka	236	41 13	43 42	1927-31, 39, 40
329	Bughdasheni	V. Orlovka	348	41 14	43 40	1949-53, 55-57

330	Kochki	V. Efremovka	168	41 12	43 45	1963-80
331	Aghri	C. Ninotsminda	187	41 16	43 36	1929-32, 49-52
332	Murjakhetistskali	V. Kulalisi	82,9	41 20	43 30	1927-35, 37-41, 49, 50
333	Murjakhetistskali	C. Akhalqalaqi	106	41 24	43 29	1929-32, 41-62
334	Baraletistskali	V. Aragva	380	41 29	43 30	1927-32, 36-39, 41-43, 45-87
335	Samsristkali	V. Merenia	45,0	41 33	43 35	1947-50, 53
336	Ablari	V. Gulikami	17.9	41 25	43 31	1950-55
337	Oshora	V. Oshora	46,0	41 37	43 15	1949-58
338	Uraveli	V. Uraveli	331	41 38	43 03	1951, 53-87
339	Fockhovistskali	V. Skhvilisi	1730	41 39	42 57	1928-32, 34-94, 97-2000, 2006
340	Kvabliani	V. Mlashe	468	41 41	42 41	1941-94
341	Kvabliani	D. Adigeni	522	41 41	42 42	1936-39, 2005, 2006
342	Kvabliani	V. Arali	908	41 39	42 51	1955-58
343	Ockhe	D. Abastumani	99,0	41 46	42 50	1936-97
344	Tsinubnistskali	V. Tsinubani	112	41 42	43 07	1962-87
345	Borjomula	V. Bakurianis-Andeziti	71,0	41 44	43 28	1931-36, 38-64, 66-94
346	Borjomula	C. Borjomi	165	41 50	43 24	1931-96
347	Gujaretistskali	D. Tsaghveri	238	41 48	43 29	1954-94
348	Baniskhevi	V. Rveli	48.0	41 53	43 25	1963-94
349	Dzama	V. Zghuderi	310	41 58	43 38	1932-46, 48-80
350	Suramula	D. Surami	54,9	42 02	43 33	1936-55
351	East Frone	V. Dvani	152	42 10	43 53	1943-94
352	East Frone	V. Sagholasheni	235	42 04	43 54	1930, 32-39, 41, 42
353	Didi-Liakhvi	V. Qvemo Roka	204	42 28	44 05	1986, 87-90, 91
354	Didi-Liakhvi	D. Java	646	42 24	43 56	1929-85, 86
355	Didi-Liakhvi	V. Kekhvi	924	42 20	43 56	1928-35, 42-67, 69-90
356	Didi-Liakhvi	C. Ckhinvali	1030	42 14	43 59	1928-42
357	Liakhvi	C. Gori	2440	41 59	44 07	1985-92
358	Borgnisi	V. Borgnisi	7,40	42 26	43 58	1946-48
359	Gudisistskali	V. Qvemo Khvtse	90,0	42 24	43 58	1945-64
360	Patara-Liakhvi	V. Vanati	422	42 17	44 04	1928-47, 49-52, 55-86
361	Mejuda	V. Rhromi	183	42 10	44 14	1928-34, 37-91
362	Mejuda	C. Gori	650	41 59	44 07	1983-96
363	Kirbalula	V. Bershueti	16.0	42 07	44 17	1935-38
364	Tana	V. Ateni	283	41 55	44 06	1937-98
365	Balavnistskali	V. Ormoci	33,3	42 08	44 39	1948-55
366	Tedzami	V. Rkoni	226	41 49	44 14	1943-58
367	Tedzami	V. Geranaschala	315	41 51	44 14	1931-34, 37-42
368	Lekhura	V. Igoeti	220	41 58	44 25	1964-91, 92
369	Lekhura	V. Mrgvali-Chala	242	41 58	44 25	1942-45, 47-64
370	Ksani	V. Pavliani	135	42 22	44 29	1948-56

371	Ksani	V. Korinta	461	42 11	44 29	1930-35, 38, 39, 41-2003, 2005
372	Ksani	C. Akhalgori	612	42 07	44 29	1966-69, 72-86
373	Ksani	V. Qsovrisi	736	42 00	44 30	1967-87
374	Aragvi	V. Cikhisdziri	760			1973-80
375	Aragvi	D. Chinvali	1900	42 08	44 47	1914, 15, 28-34, 36-70
376	Aragvi	Zhinvali HPP	1900	42 08	44 47	1985, 89-91
377	Aragvi	V. Chinti	1900	42 08	44 47	1976-86, 87, 90, 91
378	Aragvi	V. Natakhtari	2700	41 52	44 44	1931-33, 35-38
379	Mtiuletis-Aragvi (White Aragvi)	V. Mleta	107	42 26	44 30	1935, 37, 38, 42, 44-93
380	Mtiuletis-Aragvi (White Aragvi)	D. Pasanauri	335	42° 20	44° 41	1937-2011
381	Khadiskhevi	V. Tskere	18,8	42 29	44 32	1958-86
382	Gudamakris-Aragvi (Black Aragvi)	At the mouth	235	42° 21	44° 42	1939-2011
383	Arkala	V. Tandilaantkari	19,0	42 08	44 39	1948-53
384	Arkala	V. Zotiantkari	43.0	42 09	44 43	1972-78
385	Khorkhula	V. Lausha	51.8	42 12	44 46	1972-78
386	Fshavis-Aragvi	V. Magharoskari	736	42° 17	44° 52	1958-2011
387	Fshavis-Aragvi	V. Tvalivi	905	42 13	44 50	1972-77
388	Fshavis-Aragvi	At the mouth	946			1977-80
389	Khevsuretis-Aragvi	V. Barisakho	241	42 28	44 56	1935-37
390	Vere	C. Tbilisi	178	41 43	44 46	1914-20, 25, 26, 29-32, 41-55, 63-2011
391	Sackhenisi	V. Akhalsopeli	17,4	41 46	45 05	1948-54
392	Algeti	V. Madani	97.0			1990-99
393	Algeti	V. Parckhisi	359	41 35	44 35	1938, 40-90
394	Algeti	V. Shavsakdari	474			1930-37
395	Qcia-Khrami	V. Kushchi	408	41 37	43 54	1946-87
396	Qcia-Khrami	V. Ediqilisa	544	41 36	43 56	1946-93
397	Qcia-Khrami	V. Guniakala	709	41 37	43 58	1939, 40, 46, 47
398	Qcia-Khrami	C. Tsalka	1080	41 36	44 06	1927-47
399	Qcia-Khrami	V. Dashbashi	1080	41 34	44 06	1939, 40, 46-62
400	Tail race (Qcia-Khrami)	General building of the Xrami HPP	1140	41 33	44 08	1949-72, 75-93, 94, 97
401	Khrami HPP Spillway Outlet Channel	Settement of the Xrami HPP		41 33	44 08	1948-68, 75-87, 93, 94, 96, 97
402	Kcia-Khrami	V. Trialeti	1140	41 33	44 08	1929-40, 45-56
403	Kcia-Khrami	V. Kakliani	1400	41 32	44 16	1930-33, 45-47, 49-56
404	Kcia-Khrami	V. Chatakhi	1420	41 27	44 27	1956-87
405	Kcia-Khrami	V. Tsknari	1890	41 28	44 19	1932-35
406	Kcia-Khrami	V. Dagheti	2150	41 30	44 32	1938-98
407	Kcia-Khrami	V. Nakhiduri (Arukhlo)	20240			1927-38

408	Kcia-Khrami	V. Imiri	3840	41 24	44 50	1941-83, 85, 86-89, 2000, 2003, 2004, 2006
409	Kcia-Khrami	Tsiteli-Xidi (Red Brige)	8260	41° 20	45° 03	1927-35, 39-93
410	Ozni	V. Kushchi	144	41 37	43 54	1961-76
411	Nardevani	V. Nardevani	60,2	41 15	43 54	1949-56
412	Tiakilisa	V. Tiakilisa	39,2	41 16	43 59	1948-61, 78-82
413	Aghri	Above V. Beshtasheni	184	41 37	44 07	1939-92, 93
414	Korsuchai	V. Beshtasheni	47,8	41 36	44 07	1947-61, 82
415	Jujiani	D. Trialeti	126	41 32	44 10	1930-33, 1950-85, 86
416	Shavtskarostskali	V. Akha	290	41 26	44 08	1932-35, 45-56, 60-64
417	Shavtskarostskali	V. Kizilajlo	328	41 26	44 08	1954-67, 70-72, 75-92
418	Aslanka	V. Jigrasheni	42,2	41 34	44 21	1946-58
419	Mashavera	V. Didi Dmanisi	570	41 22	44 22	1941-93
420	Mashavera	D. Kazreti	690	41°23	44°25	1977-81, 83-2011
421	Bolnisistskali	V. Samtsevrisi	292	41 21	44 31	1936, 37, 41-93, 94, 97, 98
422	Shulaveri	D. Naghvarevi (Shaumiani)	116	41 19	44 35	1928-35, 41-47, 49-88, 90, 91, 92, 93
423	Debeda	V. Sadakhlo	3790	41 14	44 48	1931-34, 36, 39, 40, 54-93
424	Iori	V. Lelovani	494	42 02	44 59	1964-94
425	Iori	V. Ukughmarti	498	42 03	44 59	1934-44, 46-63
426	Iori	D. Sioni	567	42 00		1927-32
427	Iori	V. Orkhevi	587	41 58	45 02	46-61, 63-92, 98, 99
428	Iori	V. Pepenasmorevi	847	41 54	45 09	1937-1939
429	Iori	V. Sasadilo	847	41 52	45 08	1956-62
430	Iori	V. Paldo	970	41 50	45 09	1925-32, 47-52
431	Iori	V. Sartichala	1120	41 43	45 11	1960-64
432	Iori	At the Kazaniani mountain	1340	41 42	45 16	1937, 39-41, 44, 46-48, 51-60
433	Iori	C. Sagarejo	1350			1912-29, 46-53
434	Iori	V. Iormughanlo	1810	41 37	45 33	1933-35
435	Iori	P. Mglis-Chishkari	4020			1946-55
436	Verkhveli	V. Tushurebi	20,8	42 08	44 54	1947-56
437	Lapiantkhevi	V. Ujarma	48.0			1935-38
438	Alazani	V. Birkiani	282	42 13	45 19	1950-99
439	Alazani	V. Jokolo	320	42 13	45 18	1935-50
440	Alazani	V. Shaqriani	2190	41° 59	45° 34	1925-27, 33, 34, 36-44, 46-2011
441	Alazani	V. Heretiskari (Heretiskari)	4530	41 40	46 04	1925-28, 33-44, 46-97, 2003
442	Alazani	V. Zemo-Qedi	7450	41 26	46 27	1958-83
443	Samkuristskali	V. Khadori	121	42 15	45 20	1950-94
444	Ilto	V. Chartala	178	42 07	45 07	1951, 52

445	Ilto	V. Sabue	300	42 04	45 08	1953-58
446	Khevgrdzeli	V. Sabue	71,5	42 03	45 07	1953, 54
447	Stori	V. Lechuri	203	42 08	45 25	1946-49, 51-2002, 2004, 2005
448	Didkhevi	V. Artana	78.0	42 06	45 32	1946-94
449	Mghvrie	V. Shuamta	41.0			1935, 36
450	Intsoba	V. Sabue	41,4	42 02	45 41	1952-56, 58-97, 2005
451	Chelti	V. Bokinischala	50.0	42 03	45 48	1941, 42, 44, 46, 47
452	Chelti	V. Shilda	72,2	41 58	45 41	1936, 37, 41, 50-87
453	Kisiskhevi	V. Kisiskhevi	76,6	41 53	45 33	1951-54
454	Duruji	C. Kvareli	67,6	41 59	45 50	1960-80
455	Chermiskhevi	V. Mukuzani	91,8	41 48	45 53	1951-54
456	Avaniskhevi	V. Akhalsopeli	86.0	41 54	45 57	1976-81, 83-87
457	Svideba	V. Beshkendi	70.0			1930-36
458	Ninoskhevi	V. Khizabavra	37,9	41 54	46 15	1942, 44, 46-58
459	Ninoskhevi	V. Budionovka	52.4			1938-41
460	Ninoskhevi	V. Beshkendi	132			1930-36
461	Matsimi	V. Matsimi	96.0			1938-40
462	Lagodekhistskali	V. Kudigora	46.0			1935, 36, 37-40
463	Lagodekhistskali	Reservation of Lagodekhi	46.0	41 51	46 18	1981, 82-90
464	Lagodekhistskali	V. Beshkendi	254			1930-38

3 Hydrological modelling of water balance

3.1 Water balance

The hydrological cycle is a fundamental principle of hydrology. Water that evaporates from the oceans and the land surface is carried by atmospheric circulation over the earth until it eventually falls as precipitation on the land surface. In this report evaporation is used as a synonym for evapotranspiration, a collective term for all the processes by which water in the liquid or solid phase at or near the earth's surface becomes atmospheric water vapour (Dingman, 1994). Water can be stored temporarily as glaciers and snow in cold climates, on vegetation, in lakes and river systems, and as subsurface water, before it eventually discharges to the oceans as groundwater or river flow. The hydrological cycle is driven by solar energy, it involves transitions between solid, liquid and gaseous phases, and a continuous flow of water falling as precipitation on the land surface towards lower elevations under the influence of gravity. The water balance equation of any control volume of the land surface states that a difference between the volumes of inflow and outflow of water lead to changes in storage of water. The magnitudes of the water balance elements of an area of the land surface are frequently expressed as units of depths instead of volumes, e.g. the amounts of precipitation, evaporation, inflow, outflow and changes in storage for a watershed as millimetres of water for a period (Maidment, 1993).

Water plays a significant role for important sectors in modern societies, e.g. hydropower production, irrigation, water supply, tourism and transport. Furthermore, hydrological processes at the land surface influence the natural environment at a range of spatial and temporal scales through their impacts on biological activity and water chemistry. Water is also a primary weathering agent for rocks and soils, breaking them down, dissolving them, and transporting the resulting sediments and dissolved solids to the sea. Freshwater discharge and energy fluxes to the ocean, latent and sensible heat fluxes, glacier mass balance, snow cover and permafrost conditions influence the global climate through feedback effects involving atmospheric and ocean circulations (Peixoto and Oort, 1992). Assessments of water resources and impact studies in natural and social sciences where land surface hydrological conditions exert a major control on the phenomena under consideration must consider mean values, seasonal variability and extremes of water availability including snow and glaciers, subsurface moisture conditions and streamflow.

3.2 Runoff map

Assessment of runoff discharging to rivers and streams is a requirement for estimating the water resources available for hydropower production, irrigation and water supply. A map of mean annual runoff for the period 1961-1990 for Georgia is a major result of the project 'Institutional Cooperation between MOE and NEA of Georgia, and NVE' running for the period 2013-2016. Runoff is the quantity of water that discharges to river and stream channels, lakes or directly into the ocean, and it includes both surface and subsurface flow of water. For a period of several years changes in the amounts of water stored in lakes, snow and subsurface water are usually minor and runoff equals the amount of precipitation remaining after losses of water to the atmosphere by evaporation and transpiration processes. The exceptions are areas covered with glacier ice where the ablation or accumulation of ice result in changes in the amounts of storage. The map shows local runoff for a spatial resolution of one by one square kilometres in units of millimetres of water per year. Total runoff from a watershed equals the accumulated sum of runoff from the individual one square kilometre elements draining to the outlet. The runoff map is determined using results from a spatially distributed hydrological model that simulates the water balance with daily time resolution for the entire land surface of Georgia and upstream areas of watersheds in neighbour countries draining to Georgia. The model domain as well as the runoff map cover an area of 100 574 km^2 including watersheds in Turkey and Armenia. The hydrological model requires observed meteorological and hydrological data with high quality and high spatial resolution in order to supply reliable results. As the station network of meteorological and hydrological data deteriorated during the years after 1990 the period 1961-1990 was used for production of the runoff map. The hydrological model used meteorological data from 249 precipitation stations and 119 temperature stations from Georgia and upstream areas in neighbour countries. The model was set up using streamflow data from 160 hydrological stations located at the outlet of watersheds all over Georgia. The model is sensitive to spatial variability of the properties of the land surface and the meteorological input data through explicit representation of data characterizing the model domain, e.g. elevation, soil type, geology, vegetation, lakes, wetlands, glaciers, precipitation and temperature. The runoff map shows the important features of the hydrological regimes of Georgia, with humid subtropical climate of the Black Sea and steppe-continental climate of eastern Georgia, and the impacts of high elevation areas in the Caucasus mountain ranges on meteorological and hydrological processes.

3.3 Hydrological model

Hydrological precipitation-runoff models are used for applications that require simulation of the dynamic water balance of a selected area of the land surface, e.g. a watershed. They provide a capability to predict hydrological state variables and fluxes from atmospheric data, with the purpose of for example hydrological forecasts, hydrological impact simulations or management of water resources (DeVries and Hromadka, 1993). Mathematical models simplify the physical processes and replace them by a set of equations, whose solutions are programmed as a computer code. The results of simulations with the mathematical model are interpreted in terms of the physical system (Freeze, 1978). The structure of the models vary in their level of complexity, however, the major mechanisms involved in conversion of precipitation to streamflow at the catchment outlet are usually considered in one way or another. In order to be used as a tool for examining spatially distributed hydrological processes and their interactions, both vertical and lateral flow paths should be incorporated in a model. Models to be used for operationally applicable simulation systems often have a simpler structure than required by models used as research tools (Bronstert, 1999). In addition to describe the physical processes which govern storage and flow of water as subsurface and overland flow through a catchment, precipitation-runoff models must include the various hydrological and radiative processes at the land surface-atmosphere interface; interception storage, glacier mass balance, snow accumulation and snowmelt, soil evaporation and transpiration (DeVries and Hromadka, 1993). The most general way to develop a model of runoff generation processes in hillslopes is to use the complete equations of saturated and unsaturated subsurface flow and overland flow (Freeze, 1978), while channel processes are modelled using the hydrodynamic equations of unsteady flow or their dynamic wave or kinematic wave approximations. (Lettenmaier and Wood, 1993).

Most hydrological models apply an approach based on a simplified representation of the appropriate mechanisms of runoff generation and channel flow processes (Dingman, 1994), and the majority of hydrological simulation models in use are conceptual models based on a simplified representation of the real system. These models approximate catchment processes by a series of linked storages, which are usually modelled using linear or non-linear reservoirs (Shaw, 1994). Although conceptual models do not describe the mechanisms of runoff generation during rain or snowmelt events in detail, these models are in frequent use due to their low data demand. They describe the essential characteristics of precipitation-runoff processes, the volumes of water stored as snow and subsurface water are modelled correctly, and they provide realistic simulations of streamflow, the only variable in the climate system that integrates processes at the basin scale (Bergström, 1991).

Atmospheric conditions are driving the land phase of the hydrological cycle. The input data required for running a hydrological model depends on the model structure. While physically based, spatially distributed models may require data for temperature, precipitation, short and long wave radiation, humidity, wind speed, vapour pressure and other meteorological variables, conceptual models often rely on using observations of daily mean temperature and daily total precipitation from meteorological stations as input. Frequently, observations from the meteorological station network are the only reliable data available. The limited availability of input data with high spatial and temporal resolution limits the possibility for using complex model structures, and the conceptual models are usually better for practical applications as they are suited to and able to exploit the available information in the meteorological input data and the data describing land cover, soil types and other catchment characteristics (DeVries and Hromadka, 1993).

The mathematical and logical expressions used to describe the hydrological system include variables and parameters used for hydrological process simulations. Model parameters remain constant over time or vary in a manner which may be described using physical principles or empirical relationships. Parameters either represent physically measurable properties of a watershed, or are used to describe meteorological and hydrological processes. A variable may represent: (i) the state of the different storages in the hydrological system as approximated by the model; (ii) the input signal which drives the model; or (iii) the output from the model. Variables vary with time.

The water balance estimates used for constructing the map of 30-year mean annual runoff for Georgia are based on simulations with a spatially distributed version of the HBV hydrological model (Beldring et al. 2003). The HBV model (Bergström, 1995; Lindström et al., 1997) has previously been applied successfully in hydrological regimes in many parts of the world. The spatially distributed HBV model performs water balance calculations for one by one square kilometres grid cell landscape elements characterized by their elevation and land cover types. Each grid cell may be divided into two land cover zones with different vegetation and soil types, a lake area and a glacier area. The model was run with daily time steps, using precipitation and air temperature data as input. It has components for accumulation, sub-grid scale distribution and ablation of snow, interception storage, sub-grid scale distribution of soil moisture storage, evaporation, groundwater storage and runoff response, lake evaporation and runoff. Glacier mass balance is calculated for glacier covered areas of the model grid cells assuming an inexhaustible reservoir of ice. Potential evaporation and snow melt rates are functions of air temperature, The model is spatially distributed since every one by one square kilometre model element has unique characteristics that determine its parameters, input data are distributed, water balance computations are performed separately for each model element, and finally, only those parts of the model structure which are necessary are used for each element. When sub-catchment boundaries are defined, runoff from the individual model grid cells is routed to the respective outlets.

3.4 Hydrological model set up and calibration

The map of 30-year mean annual runoff for Georgia was constructed using simulations for all watersheds in Georgia draining to the Black Sea and the Caspian Sea with a spatially distributed version of the HBV hydrological model. Upstream areas of watersheds in neighbour countries draining to Georgia were included in the model domain in order to simulate the total volumes of streamflow. The model domain is characterised using digital elevation data, river network data, and land cover data, all with a spatial resolution of one by one square kilometres. The digital elevation model was resampled from ASTER data with spatial resolution 30 by 30 metres. The river network was constructed from the ASTER data with ArcGIS software. The land cover data were resampled from a classified satellite image with ten different land cover types with spatial resolution 30 by 30 metres (National Geomatics Centre of China, 2014). The land cover classes are presented in Table 3.1. All classes except Tundra are present in Georgia.

Table 3.1. Land cover classes used to describe the hydrological model domain

Land cover class	**Description**
Cultivated Land	Lands used for agriculture, horticulture and gardens
Forest	Lands covered with trees, with vegetation cover over 30%
Grassland	Lands covered by natural grass with cover over 10%
Shrubland	Lands covered with shrubs with cover over 30%
Water bodies	Water bodies in the land area, including river, lake, reservoir, etc.
Wetland	Lands covered with wetland plants and water bodies, including marsh, floodplain, forest wetland, peat bogs, etc.
Tundra	Lands covered by lichen, moss and shrubs in polar regions
Artificial surfaces	Lands modified by human activities
Bareland	Lands with vegetation cover less than 10%, including sand fields, deserts, bare rocks, saline and alkaline lands, etc.
Permanent snow and ice	Lands covered by permanent snow, glaciers and icecap

In spite of the variability of catchment properties, storm hydrographs are relatively well behaved, implying a smoothing effect at the catchment scale which overrides the effect at smaller spatial scales (Grayson et al., 1992). Similar conclusions can be drawn from the temporal variability of conservative tracers (Bonell, 1993). In small catchments and on hillslopes the effect of this integration will be less pronounced (Grayson et al., 1995). If the purpose of hydrological modelling is to simulate runoff and evaporation from large watersheds, it may not be necessary to describe the exact patterns of catchment properties and hydrological responses at small spatial scales, however, the distribution of characteristics within the catchments may still be important (Wood et al., 1988, 1990; Seyfried and Wilcox, 1995). For the hydrological model used for constructing runoff map it is nevertheless necessary to represent the exact location and characteristics of meteorological and hydrological processes at a spatial scale of one by one square kilometres. The spatial scale of the model grid is assumed to represent the essential variability of heterogeneous catchment characteristics and meteorological input data.

Due to the absence of directly measured catchment characteristics, natural variability and non-linearity of the processes involved, calibration is necessary to adjust the model parameters to improve the model's ability to reproduce the observed hydrological data. Bergström and Sandberg (1983), Lindström et al. (1997) and Colleuille et al. (2008) examined the performance of the HBV model for several water balance components, including snow storage, soil moisture in the unsaturated zone, groundwater storage and runoff using observed data on these processes. Runoff and evaporation fluxes determined by the HBV model are usually realistic when observed precipitation, temperature and streamflow data are available for model calibration. The parameter values assigned to the computational elements of the hydrological model should ideally reflect that hydrological processes are sensitive to spatial variations in soil properties (e.g. Merz and Plate, 1997) and vegetation characteristics (e.g. Matheussen et al., 2000) through their control on storage of water, runoff events, evaporation, snow and ice glacier ice accumulation and melt. However, the information contained in the precipitation-runoff data is usually not sufficient to allow identification of unique values for the parameters of a hydrological model (Jakeman and Hornberger, 1993). This identification problem makes it difficult to determine one consistent, regionally applicable parameter set (Kuczera and Mroczkowski, 1998). The digital elevation model, river network and land cover data described in Table 3.1 were used for characterising the properties of the landscape elements of the model, but due to the problem with identifying unique parameter values, all land cover classes except Water bodies and Permanent snow and ice were reclassified to either Forest or Grassland before model calibration. This reclassification procedure reduces the number of degrees of freedom in the hydrological model algorithms and simplifies determination of a regional set of model parameters to be used for ungauged catchments, while taking into account the major characteristics of vegetation and land cover types influencing snow storage and latent hear fluxes. The hydrological model was run with specific parameters for each of these four land cover classes, controlling snow accumulation and melt, interception storage, evaporation processes, soil moisture storage, groundwater storage and runoff response.

A regionally applicable set of model parameters for the distributed hydrological model of Georgia was determined by calibrating the model with the restriction that the same parameter values are used for all computational elements of the model that fall into the same class for these four land cover classes. The model was calibrated using available information about climate and hydrological processes from 160 hydrological stations in Georgia with reliable observations, and parameter values were transferred to other basins based on the classification of landscape characteristics. This calibration procedure rests on the hypothesis that model elements with identical landscape characteristics have similar hydrological behaviour, and should consequently be assigned the same parameter values. Several automatic calibration procedures, which use an optimization algorithm to find those values of model parameters that minimize or maximize, as appropriate, an objective function or statistic of the residuals between model simulated output and observed watershed output, have been developed. The nonlinear parameter estimation method PEST (Doherty et al., 1998) was used in this study. PEST adjusts the parameters of a model between specified lower and upper bounds until the sum of squares of residuals between selected model outputs and a complementary set of observed data are reduced to a minimum. A multi-criteria calibration strategy was applied, where the residuals between simulated and observed daily runoff from 160 hydrological stations with catchment areas located in Georgia and upstream areas of watersheds in neighbour countries draining to Georgia were considered simultaneously. These catchments are located in areas with different runoff regimes and landscape characteristics and all operational modes of the hydrological model were active during model calibration, which reduces the range of uncertainty of model parameters.

Precipitation and temperature values for the model grid cells were determined by inverse distance interpolation of observations from the closest precipitation stations and temperature stations. Differences in precipitation and temperature caused by elevation were corrected by precipitation elevation gradients and temperature lapse rates. There is considerable uncertainty with regard to the variations of precipitation with altitude in mountainous terrain where orographic precipitation occurs in ascending air (Daly et al., 1994). This is probably the major source of uncertainty in the results of the hydrological model simulations. The hydrological model used meteorological data from 249 precipitation stations and 119 temperature stations from Georgia and upstream areas in neighbour countries.

4 Data

Daily mean temperature and daily precipitation sums are driving the hydrological model. The quality of the meteorological data is therefore essential for the model results. Hydrological model results to be used for calculation of mean annual runoff must provide correct water balance simulations where the volume of precipitation for any one by one square kilometre grid cell equals the sum of the volumes of evaporation, runoff and changes in storage of water. For a period of several years changes in the amounts of water stored in lakes, snow and subsurface water are usually minor and runoff equals the amount of precipitation remaining after losses of water to the atmosphere by evaporation and transpiration processes. The exceptions are areas covered with glacier ice where the ablation or accumulation of ice result in changes in the amounts of storage. Hydrological data play a crucial role in setting up, calibration and validating the hydrological model. Meteorological as well as hydrological data should therefore be representative of the model domain areas, have continuous records for the entire model period, and have minimum sampling and measurement errors. In year 1989 most of the hydro-meteorological services in Georgia broke down and has only partly been re-established after year 2006. In order to have sufficient data for setting up and running the hydrological model it was decided to use the period 1961-1990 for the map of mean annual runoff for Georgia.

4.1 Meteorological data

Data from the 203 meteorological stations in Table 2.9 were subject to quality control by visual inspection and comparison with neighbour stations. Occurrence of trends and periodic variations were considered, as well as shifts and gaps in the records. Provided the data have good quality and at least ten years of data within the period 1961-1990, the stations were accepted. In order to model watershed areas draining to Georgia from upstream areas in Turkey and Armenia, meteorological data from Turkish State Meteorological Service (DMI stations) and Turkish General Directorate of State Hydraulic Works (DSI stations). The meteorological stations in Turkey are listed in Table 4.1.

Table 4.1. Meteorological stations in Turkey

	DMI Stations in Erzurum					
		Temperature	Precipitation			
Station Number	Station Name	Measurement Interval	Measurement Interval	Altitude	UTM 38 East	UTM 38 North
17096	Erzurum	1960-2004	1960-2004	1758	180896	4425184
3080	Dumlu	1986-1990	1964-1990	1825	190126	4441485
3814	Çat (Oyuklu)	1984-1997	1960-1998	1920	155176	4392926
2140	Şenkaya		1963-1989	1850	275665	4494030

3636	Söylemez		1977-1980	1850	312990	4404140
3084	Pasinler	1965-2000	1960-2000	1660	216794	4431178
8	Ovacık(Üçköşe)		1968-1976	2200	160932	4457570
1651	Olur		1960-2001	1300	258288	4524211
17668	Oltu	1964-1990	1960-2001	1322	244558	4493179
2470	Narman		1960-1983	1700	233888	4471319
3828	Karayazı		1960-1983	2360	255645	4398345
17666	İspir	1964-1994	1960-2001	1222	160937	4489095
4543	Halil Çavuş		1968-1985	1900	223921	4351252
4003	Gökoğlan	1986-1994	1965-1994	2175	179122	4382623
1971	Çamlıkaya		1965-1990	1250	175874	4506974
	DMI Stations in Artvin					
		Temperature	Precipitation			
Station Number	Station Name	Measurement Interval	Measurement Interval	Altitude	UTM 38 East	UTM 38 North
1647	Demirkent		1965-1988	500	226167	4530892
1322	Zeytinlik	1987-1994	1968-1994	350	236929	4556441
918	Veliköy		1969-1983	1350	285166	4577089
1016	Ortacalar		1969-1987	350	197113	4576522
825	Meydancık		1963-1983	1420	270172	4588663
818	Kemalpaşa		1968-1999	75	210566	4598218
1017	Dikyamaç		1960-1982	250	192846	4574847
911	Borçka	1987-2001	1960-2001	120	222595	4584771
907	Arhavi		1960-1991	10	191843	4584160
1166	Ardanuç	1964-2001	1960-2001	520	252386	4557754
	DMI Stations in Ardahan					
		Temperature	Precipitation			
Station Number	Station Name	Measurement Interval	Measurement Interval	Altitude	UTM 38 East	UTM 38 North

17630	Ardahan	1961-1995	1960-2003	1829	308300	4554221
1329	Yalnızçam		1964-1986	1850	289949	4549169
29	Meryemköyü		1965-1981	1950	333531	4555454
1034	Kurtkale		1964-1989	1700	343641	4570041
31	Hasköy		1964-1970	1975	321890	4537214
1031	Hanak		1963-1989	1840	319815	4566889
1824	Göle		1960-1981	2000	298945	4519289
34	Eşmepınar		1964-1981	1900	346082	4553328
1337	Doğruyol		1965-1983	1975	359969	4547496
922	Damal		1964-1984	2100	318742	4579876
1177	Çıldır		1960-1988	1880	339208	4559030
	DMI Stations in Kars					
		Temperature	Precipitation			
Station Number	Station Name	Measurement Interval	Measurement Interval	Altitude	UTM 38 East	UTM 38 North
17098	Kars	1960-2001	1960-2001	1775	339280	4497940
752	Binbaşı Eminbey		1967-1990	1350	315128	4602188
40	Yakınsuköyü		1965-1977	1950	350356	4556941
17692	Sarıkamış	1963-1995	1960-2001	2102	293295	4467597
2654	Kötek	1991-1994	1969-1994	1350	331234	4453692
2647	Karaurgan		1967-1983	1775	268940	4459046
2928	Karakurt		1966-1993	1500	295626	4449018
2933	Kağızman	1965-1991	1960-1991	1400	341045	4447926
46	Dil(D.Ü.Ç.)	1960-1981	1960-1981	824	464321	4403793
2485	Digor	1968-1983	1962-1983	1725	365570	4469658
17656	Arpaçay	1968-2001	1960-2001	1687	358106	4523469
1834	Akyaka (Kızılcakcak)		1963-1987	1500	384598	4510053

	DMI Stations in Bayburt					
		Temperature	Precipitation			
Station Number	Station Name	Measurement Interval	Measurement Interval	Altitude	UTM 38 East	UTM 38 North
2280	Aydıntepe (Hart)	1989-2000	1967-2000	1500	88352	4483462

Table 4.2. Turkish General Directorate of State Hydraulic Works stations

	DSI Stations in Erzurum				
		Precipitation			
Station Number	Station Name	Measurement Interval	Altitude	UTM 38 East	UTM 38 North
23005	Yolboyu	1964-1968	1150	272526	4436714
24001	Yeniköy	1973-1998	2190	225735	4441967
21002	Yarmak	1963-1972	1750	152397	4394906
23009	Tortum HES	1974-2002	1020	216680	4503452
21066	Şenyurt	1976-1996	2210	200591	4454039
21074	Parmaksız	1992-1999	1760	214397	4366417
23001	Kömürlü	1963-2004	1430	272057	4514513
21013	Kırkgöze (Çıpak)	1963-1976	1825	191773	4446979
24002	Hacıömer	1963-1996	1830	222439	4390209
21071	Hacımahmut	1981-1996	1980	133249	4414344
23006	Gölbaşı (Öşk)	1966-1972	1010	215199	4501655
21073	Burhan	1984-1996	1630	231367	4358401
24015	Bulkasım	1972-2003	1840	210749	4422140
21056	Bingöze	1973-1995	2190	168353	4464657
	DSI Stations in Artvin				
		Precipitation			
Station Number	Station Name	Measurement Interval	Altitude	UTM 38 East	UTM 38 North

23004	Sarıgöl	1964-1999	1300	198381	4539393
23002	Damar	1964-1972	1100	216513	4572032
	DSI Stations in Ardahan				
		Precipitation			
Station Number	Station Name	Measurement Interval	Altitude	UTM 38 East	UTM 38 North
24008	Yiğit Konağı	1966-1994	1995	296593	4536019
24013	Gülyüzü (Pekrenis)	1968-1998	2000	351380	4538410
24016	Buğatepe (Büyük)	1976-1998	2210	321442	4518711
	DSI Stations in Kars				
		Precipitation			
Station Number	Station Name	Measurement Interval	Altitude	UTM 38 East	UTM 38 North
24007	Kırıkpınar	1964-1972	2210	334221	4523967
24003	Geçit	1966-1974	1544	377622	4513867
24009	Çaybaşı (Suphanazat)	1966-1972	1810	326118	4477873
24004	Buruksu	1962-1972	1350	387553	4424888
24012	Pazarcık	1976-1998	2100	357256	4479065
24018	Kocaköy (Digor)	1983-1998	1610	372239	4445484
24011	Bozkuş	1974-1998	2215	140545	4506745
24019	Arpaçay Barajı	1984-1993	1460	384281	4489702
	DSI Stations in Bayburt				
		Precipitation			
Station Number	Station Name	Measurement Interval	Altitude	UTM 38 East	UTM 38 North
23010	Ozansu	1973-1999	1750	73628	4449002
23008	Sarımeşe	1969-2002	1700	100069	4490251

After quality control of data from the meteorological stations in Georgia and Turkey, data from 249 precipitation stations and 119 temperature were accepted for use as input to the hydrological model. The selected stations are shown in Figure 4.1.

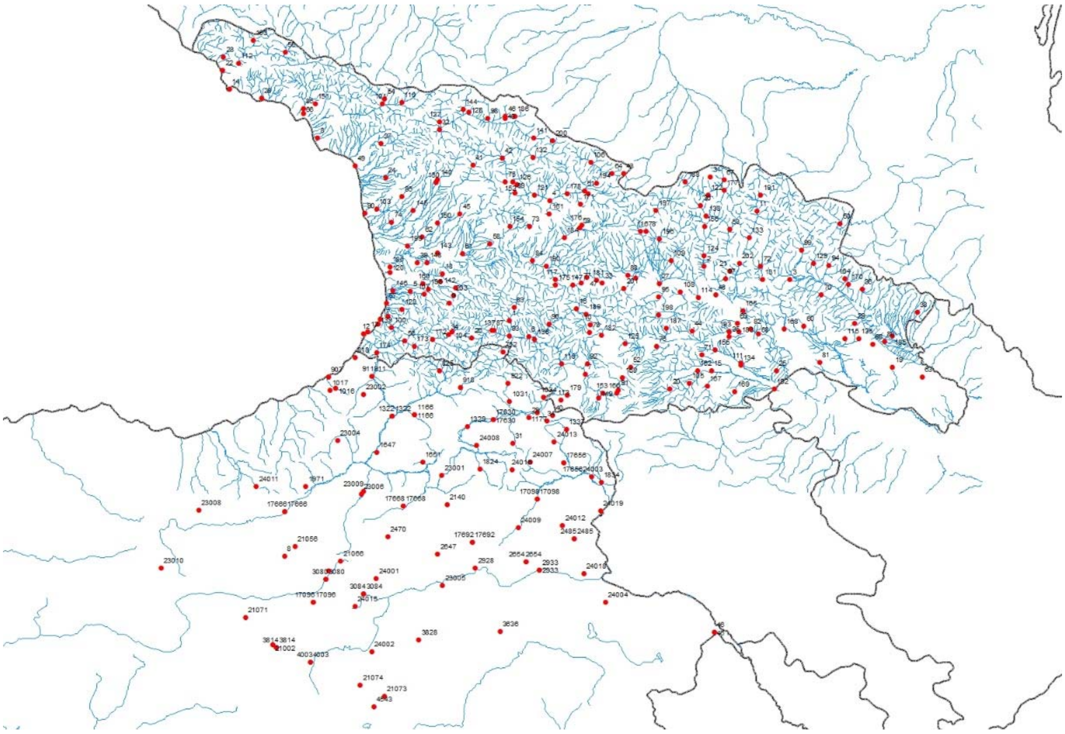

Figure 4.1. Meteorological stations in Georgia and Turkey used as input to the hydrological model.

4.2 Hydrological data

Data from the 464 hydrological stations in Georgia listed in Table 2.11 were subject to quality control by visual inspection and comparison with neighbour stations. Occurrence of trends and periodic variations were considered, as well as shifts and gaps in the records. Provided the data had good quality and at least ten years of data within the period 1961-1990 the stations were accepted. Quality control of data from the hydrological stations resulted in streamflow data from 160 hydrological stations located at the outlet of watersheds all over Georgia to be accepted for use for calibration and validation of the hydrological model. The selected stations are shown in Figure 4.2 and the stations and their upstream sub-catchments in Georgia, Turkey and Armenia is shown in Figure 4.3.

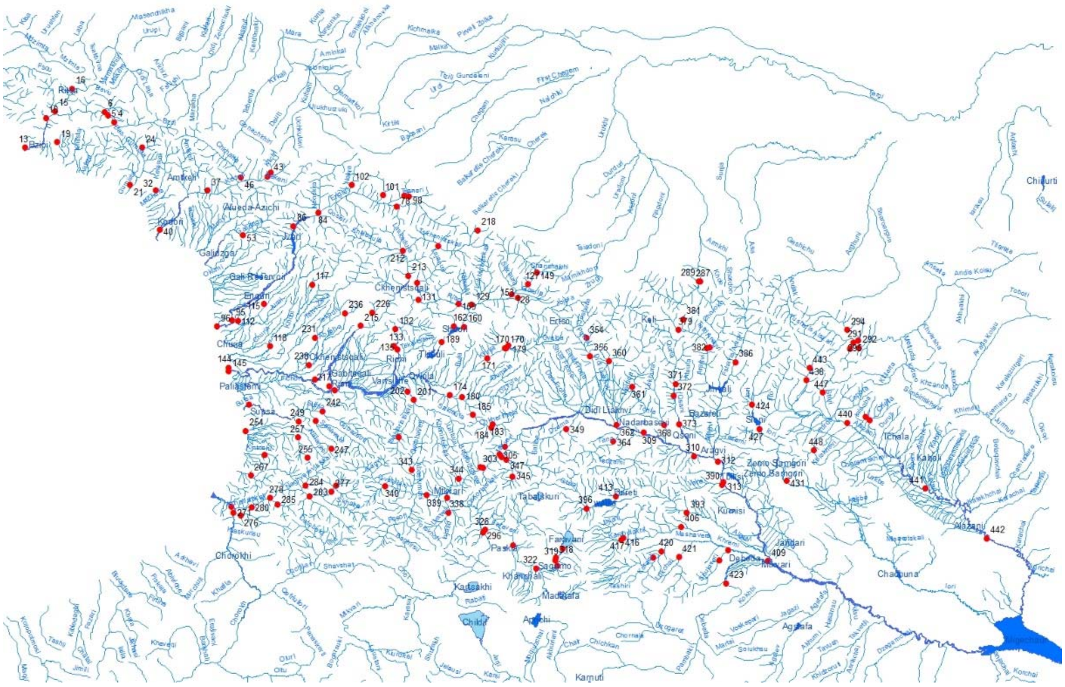

Figure 4.2. Hydrological stations in Georgia used for calibration and validation of the hydrological model.

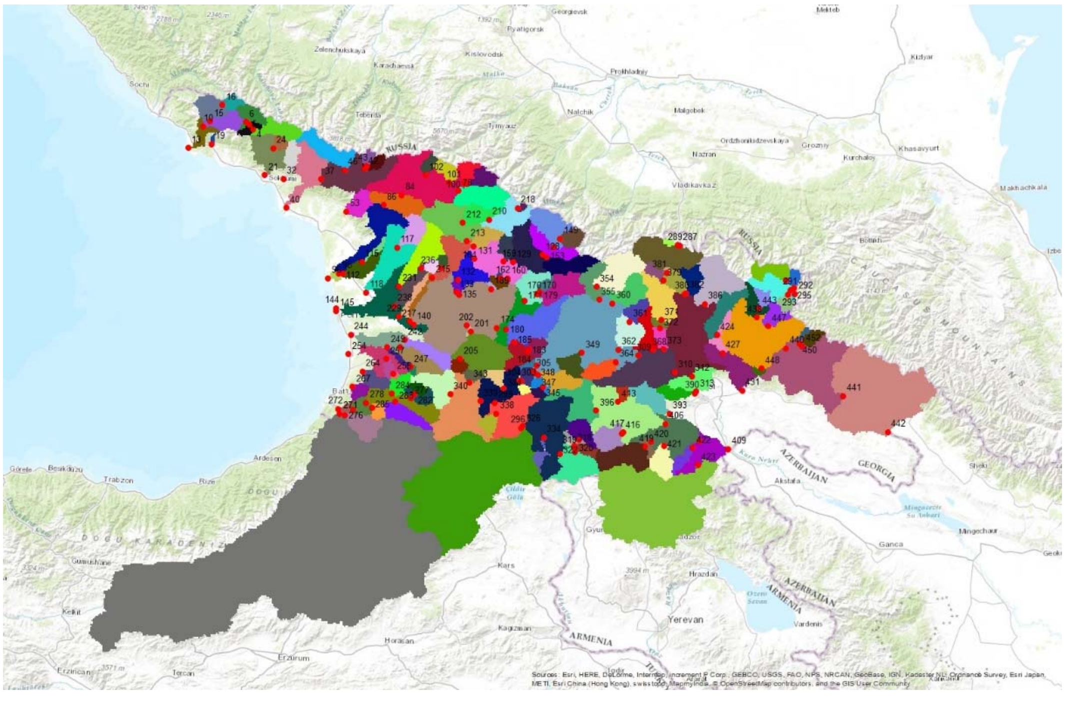

Figure 4.3. Hydrological stations in Georgia used for calibration and validation of the hydrological model and their upstream sub-catchments in Georgia, Turkey and Armenia.

5 Results

The runoff map is determined using results from a spatially distributed hydrological model that simulates the water balance with daily time resolution for the entire land surface of Georgia and upstream areas of watersheds in Turkey and Armenia draining to Georgia. The model domain as well as the runoff map cover an area of 100 574 km^2 including watersheds in Turkey and Armenia. Upstream areas in Turkey and Armenia were included in the model domain in order to simulate the total volumes of streamflow. As the station network of meteorological and hydrological data in Georgia deteriorated during the years after 1990, the period 1961-1990 was used for running the hydrological model providing the water balance simulations used for producing the runoff map. However, most time series from the meteorological and hydrological station network in Georgia also have gaps in the records for the period 1961-1990. It is possible to calibrate and validate the hydrological model using observed streamflow time series with gaps in the records, but the meteorological input time series to all one by one square kilometre hydrological model grid cells must be complete. In order to determine continuous meteorological input time series it was necessary to include observations from the 11 meteorological stations closest to each grid cell in the spatial interpolation procedure. Although some stations are missing observed data for a given day, other stations will have observed data for the same day. The inverse distance interpolation procedure was therefore able to calculate input temperature and precipitation to the hydrological model grid cells for all days in the period 1961-1990.

5.1 Hydrological model results

The purpose of calibration is to adjust the model parameters in order to improve the performance of the model with respect to reproducing observed data. Model performance is usually evaluated by considering one or more objective statistics or functions of the residuals between model simulated output and observed sub-catchment output. The objective functions used in this study were the Nash-Sutcliffe and bias statistics of the residuals, which have a low correlation (Węglarczyk, 1998). The Nash-Sutcliffe efficiency criterion ranges from minus infinity to 1.0 with higher values indicating better agreement. It measures the fraction of the variance of observed values explained by the model. Bias (relative volume error) measures the tendency of model simulated values to be larger or smaller than their observed counterpart. Although the Nash-Sutcliffe efficiency criterion is frequently used for evaluating the performance of hydrological models, it favours a good match between observed and modelled high flows, while sacrificing to some extent matching of below-mean flows. It is for this reason that two different measures of model performance were considered. Results for model performance (Nash-Sutcliffe and bias statistics) using observed precipitation and temperature data for the calibration period 1961-1990 are acceptable for many sub-catchments, while for others model performance is not acceptable. The Nash-Sutcliffe efficiency criteria for the individual sub-catchments ranged from -25 to 0.74, while the bias ranged from -0.92 to 2.38. Therefore it was necessary to correct model results within the individual sub-catchments in order to reduce the bias between mean annual streamflow based on observed data and model simulations. The ratios between observed mean annual runoff and simulated mean annual runoff were determined for the 160 catchments with reliable observations. If the catchments were nested, runoff from the inter-station sub-catchments were used. These ratios were applied as correction coefficients for the water balance calculations for each grid cell, but these coefficients were limited to the range from 1.0 to 1.2 in order not to introduce unrealistic values. The quality of streamflow time series from Georgia suffer from extraction of water from the watersheds and limited quality control of measurements including hydraulic controls, channel cross sections and rating curves, and should be used with care. A similar procedure was used by Fekete et al. (1999) when calculating monthly runoff for the entire global land surface at 30-minute spatial resolution. After this correction procedure had been applied, the Nash-Sutcliffe efficiency criteria for the individual sub-catchments ranged from -39 to 0.61, while the bias ranged from -0.89 to 3.32. Although the range of values for the two objective criteria did not change substantially after the correction procedure, the overall results are better, with higher values for the Nash-Sutcliffe efficiency criteria and smaller spread around zero for the bias.

An independent period should ideally be used for evaluating model performance under non-stationary conditions stationarity as defined by (Klemeš, 1986). Non-stationarity means that a significant change in climate, land cover or other basin characteristics occurs. The meteorological and hydrological records are too short to allow a sufficiently long independent period for evaluation of model performance. An alternative would be to exclude some stations from the calibration procedure and evaluate model performance for these independent catchments. However, all meteorological and hydrological data with acceptable quality were used for setting up the hydrological model and producing the runoff map in order to reduce the deviations from observed streamflow data.

The hydrological model simulated total streamflow volumes for the catchments upstream each of the 160 hydrological stations used for setting up the model. The model also simulated temperature and water balance elements for the inter-station sub-catchments: precipitation, snow storage, glacier mass balance, evaporation, soil moisture deficit, groundwater storage and runoff. Figures 5.1 and 5.2 show model results for the catchment upstream station 128 Rioni C. Oni with area 1060 km^2 for the period 1961-1990.

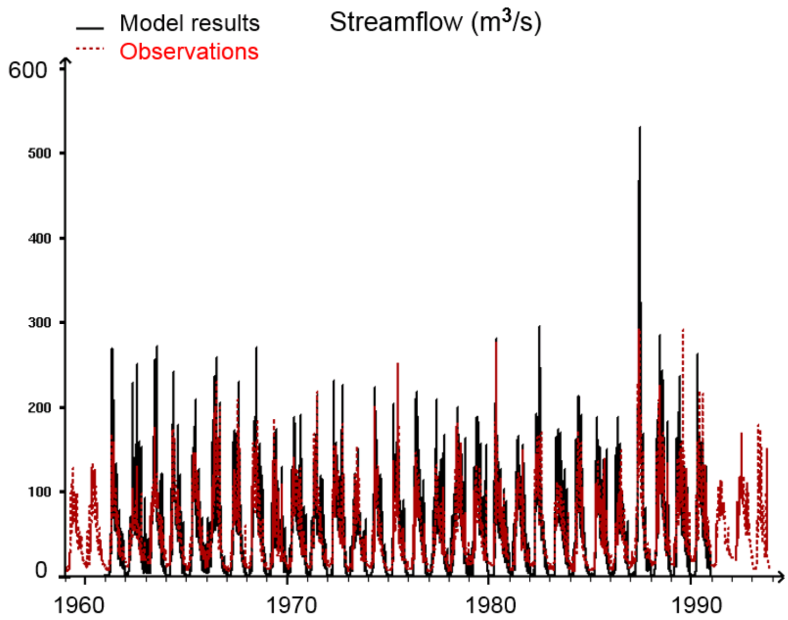

Figure 5.1. Streamflow from catchment upstream hydrological station 128 Rioni C. Oni

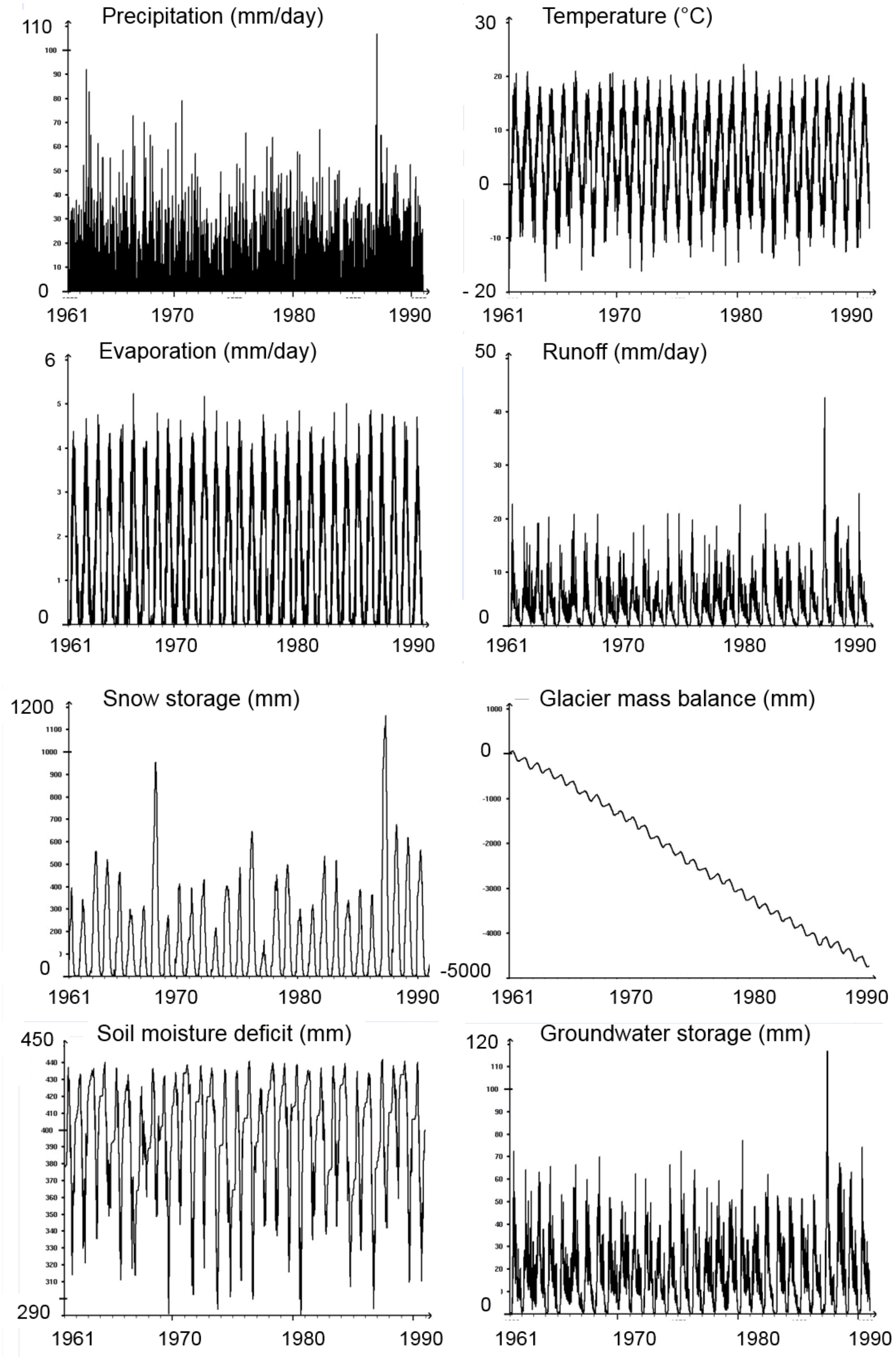

Figure 5.2. Temperature, precipitation, evaporation, runoff and other water balance elements for sub-catchment upstream hydrological station 128 Rioni C. Oni, area 1060 km^2, elevation range 819 to 4037 metres above sea level

Streamflow simulated by the model agrees well with observed data, as shown by Figure 5.1. Although the model is unable to simulate daily streamflow with the same precision for all 160 catchments, the agreement between the total volumes of simulated and observed streamflow mostly agrees well after the correction procedure based on the ratios between observed mean annual runoff and simulated mean annual runoff. Streamflow is equal to runoff multiplied by catchment area and model results for mean annual runoff are therefore mostly accurate. The elevations in catchment 128 Rioni C. Oni ranges from 819 to 4037 metres above sea level and includes high elevation areas with glaciers in the Greater Caucasus mountain range. Figure 5.2 shows that the temperature falls below the freezing point for several months during winter, large amounts of precipitation accumulates as snow and a period of low flow occurs. During spring and early summer snowmelt is an important hydrological event generating large streamflow and floods as shown by the Figure 5.1. However, heavy precipitation during summer is also responsible for large floods. Although evaporation from the catchment is moderate a substantial soil moisture deficit develops during summer, reaching its maximum during late summer or early autumn. The groundwater storage is a result of infiltration of water from rain or snowmelt, it controls the runoff generation dynamics in the catchment, and it generally follows the same annual cycle as streamflow. Mean annual glacier mass balance is approximately minus 160 millimetres of water equivalent, indicating that glaciers in the catchment are wasting their ice volume and retreating.

5.2 Runoff map

The runoff map for the period 1961-1990 is based on averaging results from a distributed hydrological model that simulates the water balance with daily time resolution for one by one square kilometre grid cells for the entire land surface of Georgia and upstream areas in Turkey and Armenia draining to watersheds in Georgia. The model results include all water balance elements of the land phase of the hydrological cycle, including the precipitation, evaporation and runoff, as well as the various storage elements at or below the earth's surface. The model domain covers an area of 100 574 km^2. The upstream areas in Turkey and Armenia were included in the model domain in order to simulate the total volumes of streamflow from the watersheds in Georgia. Maps of mean annual precipitation, evaporation and runoff are shown in Figures 5.3, 5.4 and 5.5.

Due to the variable topography and climate regimes in Southern Caucasus, precipitation is highly variable in space, both in terms of annual totals and seasonal distribution. The topographic features are highly variable, ranging from coastal plains to mountain ranges reaching above 5000 metres above sea level. Mean annual precipitation in Georgia varies from less than 500 mm to approximately 4000 mm per year. In southwest the seasonal distribution has a maximum in autumn and a minimum in spring. In eastern Georgia maximum precipitation occurs in spring, while a second, smaller maximum occurs in autumn. In western Georgia the combined influence of the Black Sea and the orographic effect is evident. In the Black Sea lowland the mean annual precipitation is about 1500 mm, to the north on the southern slopes of the Greater Caucasus mountain range it rises to above 2000 mm. To the south of the lowland the mean annual precipitation rises to 4000 mm on the high grounds east of the city of Batumi. In eastern Georgia, beyond the barrier formed by the Likhi range, mean annual precipitation varies in general between 500 and 1000 mm, although it reaches 1600 mm along the crest of the mountains north of the capital Tbilisi (Sutcliffe et al., 2008).

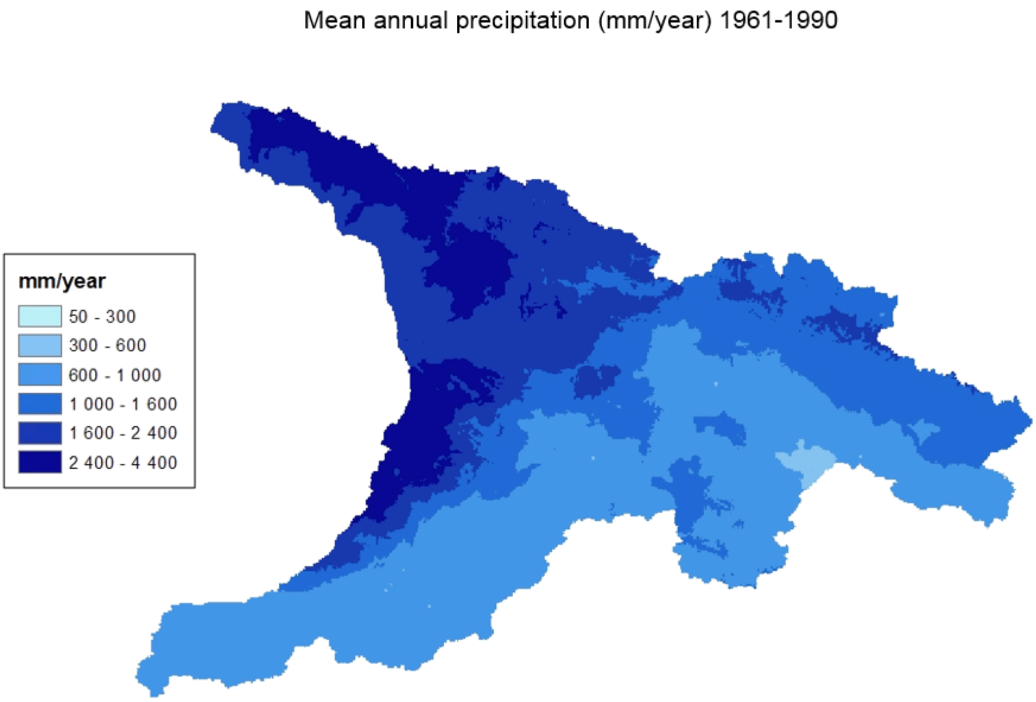

Figure 5.3. Mean annual precipitation (mm/year) for the period 1961-1990 for Georgia and upstream areas in Turkey and Armenia draining to watersheds in Georgia

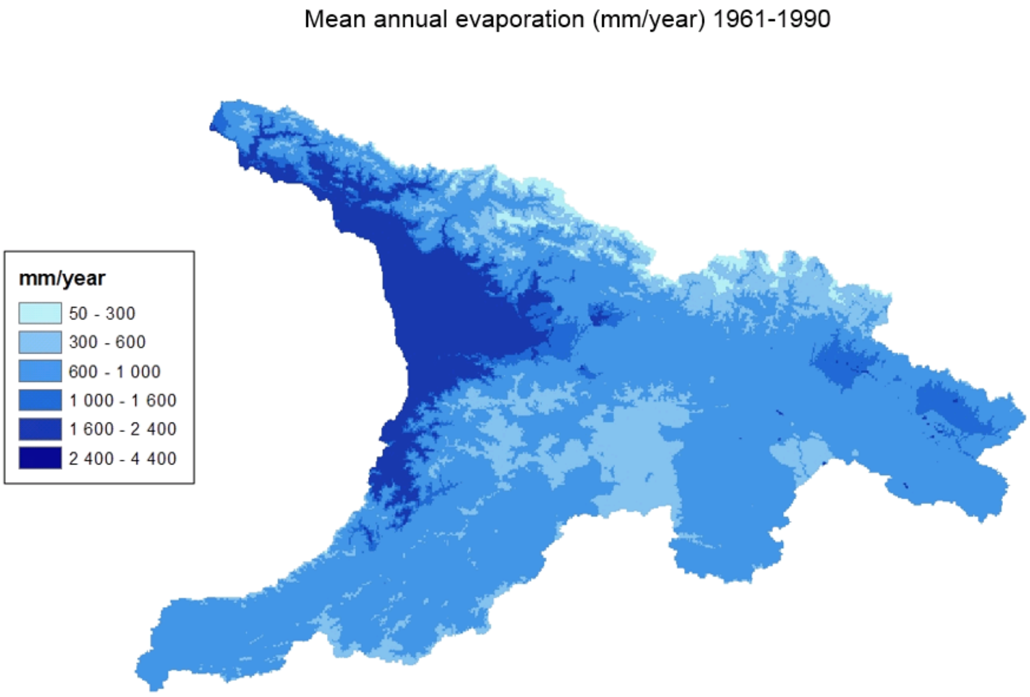

Figure 5.4. Mean annual evaporation (mm/year) for the period 1961-1990 for Georgia and upstream areas in Turkey and Armenia draining to watersheds in Georgia

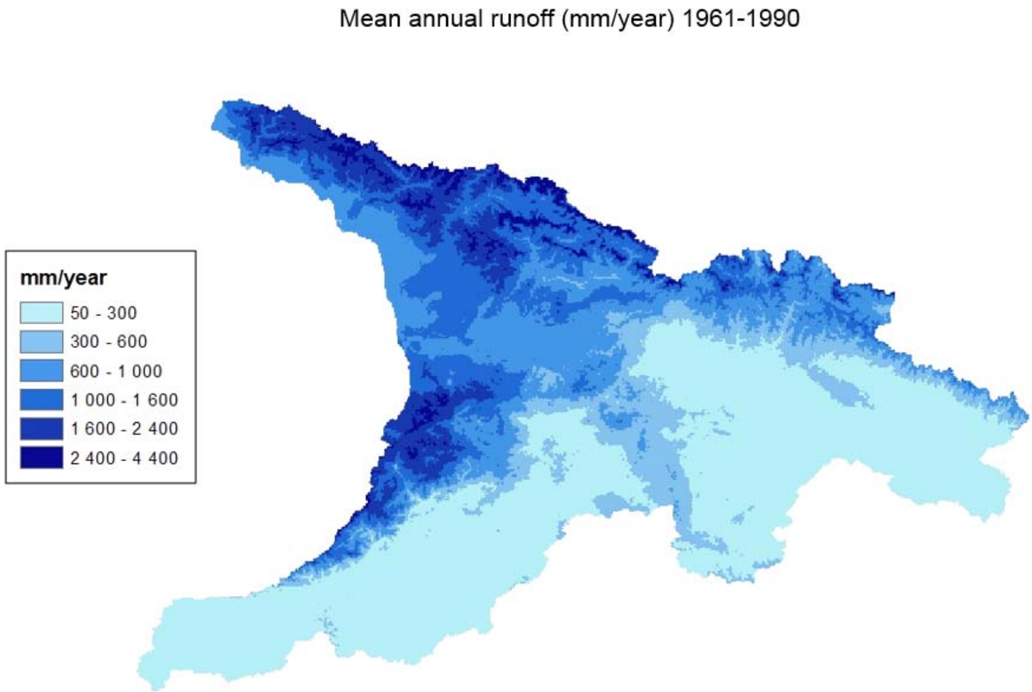

Figure 5.5. Mean annual runoff (mm/year) for the period 1961-1990 for Georgia and upstream areas in Turkey and Armenia draining to watersheds in Georgia

Mean annual evaporation values are highest in the humid western parts of Georgia bordering the Black Sea, and lowest in the high mountain regions of the Greater Caucasus mountain range. Evaporation is also small in eastern parts of Georgia and in the Lesser Caucasus mountain ranges. This reflects the large solar radiation inputs, high temperatures and large precipitation in western Georgia, whereas the high mountain areas have lower temperatures and lower evaporation. Eastern Georgia is a dry area with annual evaporation of almost the same magnitude as annual precipitation, leaving on average less than 100 mm per year for annual runoff in some areas.

The map of mean annual runoff shows the important features of the hydrological regimes of Georgia, with humid subtropical climate of the Black Sea and steppe-continental climate of eastern Georgia, and the impacts of high elevation areas in the Caucasus mountain ranges on meteorological and hydrological processes. The uneven distribution of precipitation lead to significant difference between the major climate regions and their hydrological conditions. Large precipitation supply the abundant rivers on the southern slopes of the Greater Caucasus and the northern slopes of Lesser Caucasus in western Georgia. Less abundant rivers run from the Greater Caucasus and Lesser Caucasus mountains in eastern Georgia. Mean annual runoff of western Georgia is five to ten times larger than mean annual runoff of eastern Georgia. Mean annual runoff from catchment areas in Turkey and Armenia draining to watersheds in Georgia is also low, the exception being the western part of Turkey bordering the Black Sea. The differences in runoff are reflected in streamflow of the rivers, which is three times larger in western than in eastern Georgia.

Conclusions

A fundamental characteristic of the hydrologic cycle is that it has no beginning and no end. It can be studied by starting at any of the following processes: evaporation, condensation, precipitation, interception, infiltration, percolation, transpiration, runoff, and storage. Hydrological precipitation-runoff models usually assumes that atmospheric conditions are forcing the land phase of the hydrological cycle without feedback effects from the earth's surface, and these models therefore determine the impacts of precipitation, temperature and other atmospheric variables on storage elements and flow of water over and below the land surface. The spatially distributed hydrological model applied in this study represented these processes by including the spatial distribution of hydrological responses in the landscape in a framework that represent spatial variability explicitly by element to element variations. Computational elements with similar landscape characteristics at the model grid scale were assigned the same values for model parameters. The spatial scale of the model grid was assumed to represent the essential variability of heterogeneous catchment characteristics and meteorological input data. Calibration was performed for a period of 30 years for catchments located in areas with different climate and land surface properties. A large range of variations in runoff conditions for several landscape types and seasons where different runoff generating mechanisms dominate were considered. Model performance was mostly satisfactory for the purpose of calculating mean annual runoff for the catchments used to set up and calibrate the model.

The hydrological model simulates streamflow with daily time resolution for the entire territory of Georgia including upstream areas of watersheds in Turkey and Armenia draining to Georgia. It has the potential to be used for various purposes where hydrological processes are under consideration, e.g. simulating the impacts of climate change or land use management strategies, hydrological forecasts, pollution control, assessment of water resources available for hydropower production, irrigation, water supply. However, the quality of streamflow time series from Georgia suffer from extraction of water from the watersheds and limited quality control of measurements including hydraulic controls, channel cross sections and rating curves. These problems impact on the calibration and validation and subsequently on the performance of the hydrological model. Model results are also sensitive to the meteorological station network and the quality of the meteorological data. Precipitation and temperature are the major factors determining hydrological conditions and the performance of the model improves with higher density of meteorological stations as the ability to determine the spatial fields of precipitation and temperature improves. This is particularly important for high elevation areas where meteorological stations are frequently lacking. Although the performance of the hydrological model for the purpose of calculating mean annual runoff is mostly satisfactory, the model is not sufficiently precise for applications that require high precision for finer time resolutions. Model simulations are performed for daily time steps and the quality of meteorological and hydrological data is crucial for model performance.

Streamflow at the outlet of a sub-catchment is the integrated runoff from the individual one by one square kilometre grid cells within the water divides defining the boundaries of the sub-catchment and all upstream sub-catchments in the river network hierarchy. The integrated runoff from the model simulations generally deviate from observed streamflow at the hydrological stations at the sub-catchment outlets. The runoff map for the period 1961-1990 which is based on results from the precipitation-runoff model was therefore improved by multiplying the simulated value for each model grid cell within a sub-catchment with the ratio between observed average annual runoff and simulated average annual runoff at the outlet of the sub-catchment. This procedure was performed in an iterative process starting from the upper sub-catchments in a watershed and proceeding downstream. This procedure maintains the correction of streamflow for each individual sub-catchment while ensuring that accumulated runoff do not deviate from observed streamflow at the hydrological stations. The model results for the maps of mean annual precipitation and evaporation were corrected by multiplication with the same ratios.

Model results for mean annual precipitation, evaporation and runoff for the period 1961-1990 for the entire model domain including upstream areas in Turkey and Armenia draining to Georgia provide a consistent view of the water balance for all one by one square kilometre grid cells and watersheds in the territory of Georgia. For a period of several years changes in the amounts of water stored in lakes, snow and subsurface water are usually minor and runoff equals the amount of precipitation remaining after losses of water to the atmosphere by evaporation and transpiration processes. The exceptions are areas covered with glacier ice where the ablation or accumulation of ice result in changes in the amounts of storage. In Georgia this will occur in the high mountain areas in the Greater Caucasus mountain range. The map shows local runoff for a spatial resolution of one by one square kilometres in units of millimetres of water per year. The map of mean annual runoff for the period 1961-1990 for the territory of Georgia excluding upstream areas in Turkey and Armenia is shown in Figure 6.1.

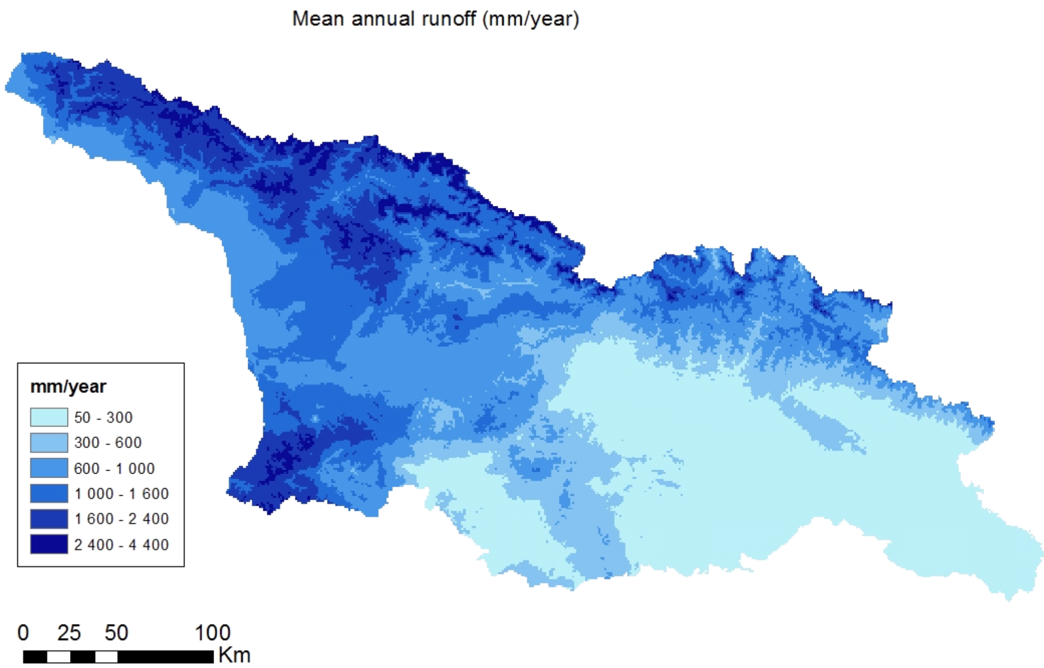

Figure 6.1. Mean annual runoff (mm/year) for the period 1961-1990 for Georgia

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