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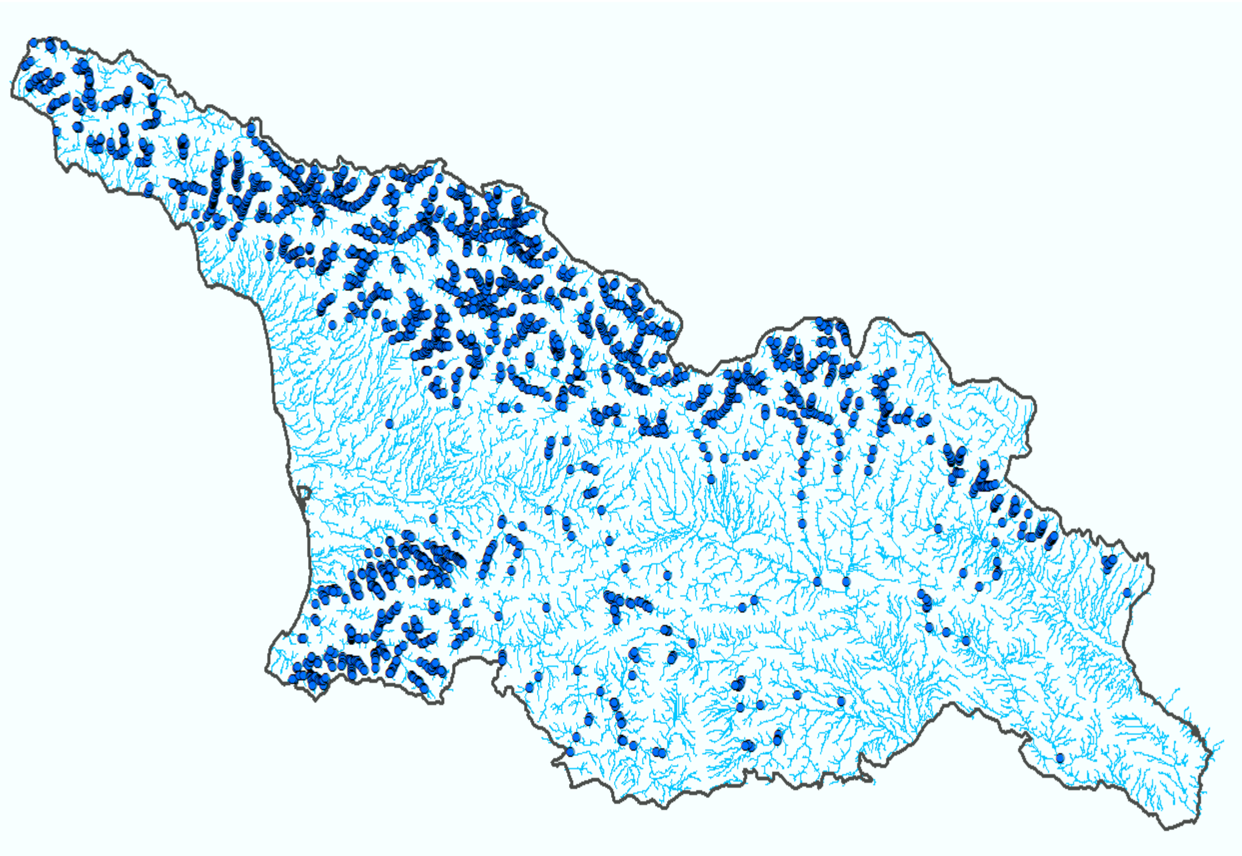
Hydro Power Potential in Georgia

Calculating the hydro power potential in Georgia using the national runoff map, an elevation model and the Cost Base for Hydro Power Plants

Fredrik Arnesen, Søren Elkjær Kristensen, Giorgi Shukakidze, Valentin Koestler, Vakhtang Geladze, Eira Taksdal, Aslak Wegner Eide



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Hydro Power Potential in Georgia : Calculating the hydro power potential in Georgia using the national runoff map, an elevation model and the Cost Base for Hydro Power Plants

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Editor: Fredrik Arnesen

Authors: Fredrik Arnesen (NVE), Søren Elkjær Kristensen (NVE), Giorgi Shukakidze (Ministry of Energy of Georgia), Valentin Koestler (NVE), Vakhtang Geladze (NEA), Eira Taksdal (NVE), Aslak Wegner Eide (NVE)

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Abstract: In this GIS-based analysis, a theoretical hydro power potential of 30 TWh was calculated. The analysis used an elevation model, a hydrological runoff map and a cost base for hydropower plants in Georgia as input. Several general assumptions were made about the outline of the identified hydro power plants, in order to utilize the cost base to exclude the most expensive schemes. Some additional filtering was carried out to exclude potential that is already developed, and to exclude potential located within national parks and other protected areas.

Key words: Hydropower, Potential, Georgia, River network

Norwegian Water Resources and Energy Directorate
Middelthuns gate 29
P.O. Box 5091 Majorstuen
N-0301 Oslo
Norway

Telephone: +47 22 95 95 95
E-mail: nve@nve.no
Internet: www.nve.no

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Contents

Preface

The assessment of the hydro power potential in Georgia is one of the final products from the institutional cooperation between the Ministry of Energy of Georgia (MOE), The National Environmental Agency of Georgia (NEA), and the Norwegian Water Resources and Energy Directorate. The project was completed in 2016.

This analysis of the hydro power potential in Georgia rests on two pillars, which both are products from the institutional cooperation project, namely the runoff map for Georgia and the cost catalogues for small and large hydro power plants in Georgia.

The hydro power potential that was identified in this analysis is intended to be used as a starting point for more detailed, local studies, that in turn can lead to identification of feasible hydro power projects.

The dataset belongs to the Ministry of Economy and Sustainable Development of Georgia (MOESD) and is temporarily hosted by NVE. The dataset was last updated in 2016.

Michael Steinfeld
Oslo, February 2021

Summary

The objective of this analysis was to map the theoretical hydropower potential in Georgia, and the technical hydropower potential that is not already developed, that is not located inside certain protected areas and that has an estimated investment cost less than $ 0.35 per annually produced kWh. It is presupposed that the hydropower potential should be exploitable without regulation magazines or dams that are built in order to increase the head.

Throughout the years, several studies of the hydropower potential in Georgia have been conducted, ranging from the most theoretical assessments of energy potential in the rivers to detailed studies. Still, an assessment of the hydropower potential based on the new national runoff map was yet to be carried out. In the initial phase of the project, the total energy potential in Georgian rivers was calculated to 84 TWh. From this, a gross theoretical hydro power potential of 56 TWh was calculated. This number includes hydropower resources already developed and resources within protected areas. In order to make the study a more practical tool for planners and investors, development costs had to be included in the analyses. Georgian and Norwegian consultants therefore subsequently prepared a cost base for hydropower plants in Georgia. In the final GIS-based analyses, several general assumptions were made about the outline of the identified hydro power plants, in order to utilize the cost base to exclude the most expensive schemes. Finally, the initial theoretical hydro power potential of 56 TWh was reduced to a total hydropower potential of 30 TWh, excluding the potential that would be too expensive to develop, potential that is already developed and potential located within national parks and other protected areas.

The identified projects should be regarded as a tool and starting point for potential investors, as well as the Georgian government, for further and more detailed local studies of the hydropower potential. The results presented in this report should be used together with the cost base for hydro power in Georgia and knowledge about the local hydrological and geological conditions.

1 Calculating Hydro Power Potential in three steps

The objective of the analysis is to answer the question "What is the hydro power potential in Georgia, without storage reservoirs, that is not located within protected areas, not already developed and that might be possible to develop with a construction cost below 0.35 USD per annually produced kWh?"

"What is the hydro power potential in Georgia, without storage reservoirs, that is not located within protected areas, not already developed and that might be possible to develop with a construction cost below 0.35 USD per annually produced kWh?"

The analysis was carried out in three steps. First, a geographical elevation model was applied to create river profiles for the whole country. Together with the new national runoff map for Georgia these river profiles were utilized in order to calculate the locations of inlets and outlets that would give the highest hydro power production. Finally, the technical-economical hydro power potential with a specific construction cost lower than $ 0.35 was calculated. The process, as well as the applied data sources, are visualized in **Figure 1:**

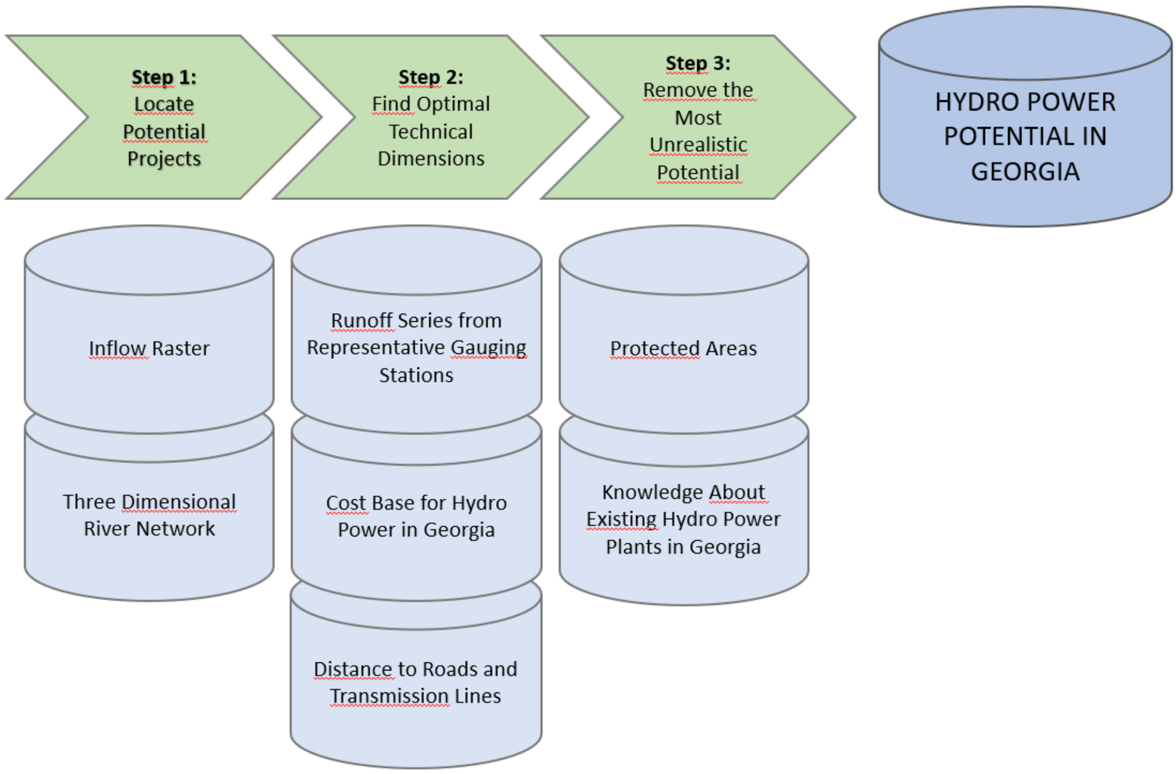

Figure 1: Calculating the hydro power potential in Georgia in three steps.

The three steps in Figure 1 are described in this chapter (Chapter 1). The river network, the inflow raster and the rasters with distances to the nearest road and to the transmission grid are described in Chapter 2. The cost function that was applied in Step 2 is based on the *Cost Base for Hydro Power Plants in Georgia* and *Cost base for Small Hydro Power Plants in Georgia* (Norwegian Water Resouces and Energy Directorate and Ministry of Energy of Georgia, 2016). The cost function itself is described in more detail in Chapter 3. The runoff series were provided by the Georgian National Environmental Agency (NEA).

1.1 Step 1: Locate Potential Projects

The first step was to locate all the theoretical hydro power potential sites in Georgia. This was done by calculating the height profile for all the rivers in Georgia. The height profile was derived from a river network and an elevation model and was utilized together with an inflow grid in order to calculate the total, gross theoretical energy potential in the country's rivers.

Step 1: "Where in the river should the inlet and outlet be placed to give the highest power output for each power plant?"

All the rivers were divided into river segments with a resolution of 50 meters, and information about the altitude and geographical location at the start and the end of each 50 meter long river segment is given in a profile table. The inflow grid contains information about the mean annual inflow to each point in Georgia and is derived from the national runoff map. Details about how the river profile and inflow grid is calculated is given in chapter 2.1.

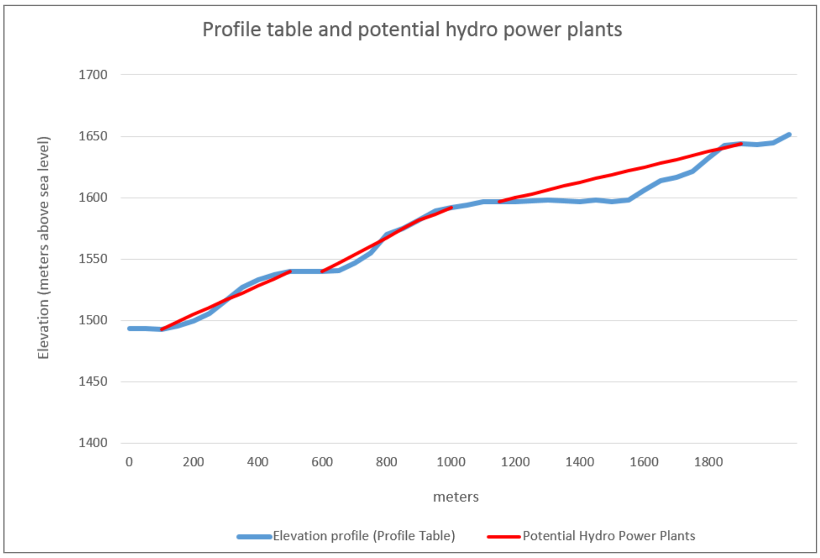

Figure 2: Example of a river profile and identified hydro power potential

The potential projects were identified by an algorithm that started out by placing the power station by the outlet point of the river, and the intake at the top of the river. Then, the algorithm investigated if the maximum power output would increase if the inlet was moved further downstream. This means, that for each river, the model identified the head that would give the maximum output from the power plant. Figure 2 shows an example of a river, where three potential hydro power plants were identified. The maximum theoretical output is given by the formula below:

$$P = \rho \cdot g \cdot Q \cdot H$$

P = Maximum power output (W)

ρ = water density (kg/m^3)

g = gravitation constant (Nm^2/kg^2)

Q = Design flow (m^3/s)

H = Gross head (m)

Since ρ and g are constants, this ammounts to optimizing the product of Q, derived from the profile table, and H, derived from the inflow grid. The water density, ρ, is $1000\ kg/m^3$. Since this is an optimization of effect, and not of energy, the design flow was set equal to 100 % of the mean inflow to the intake.

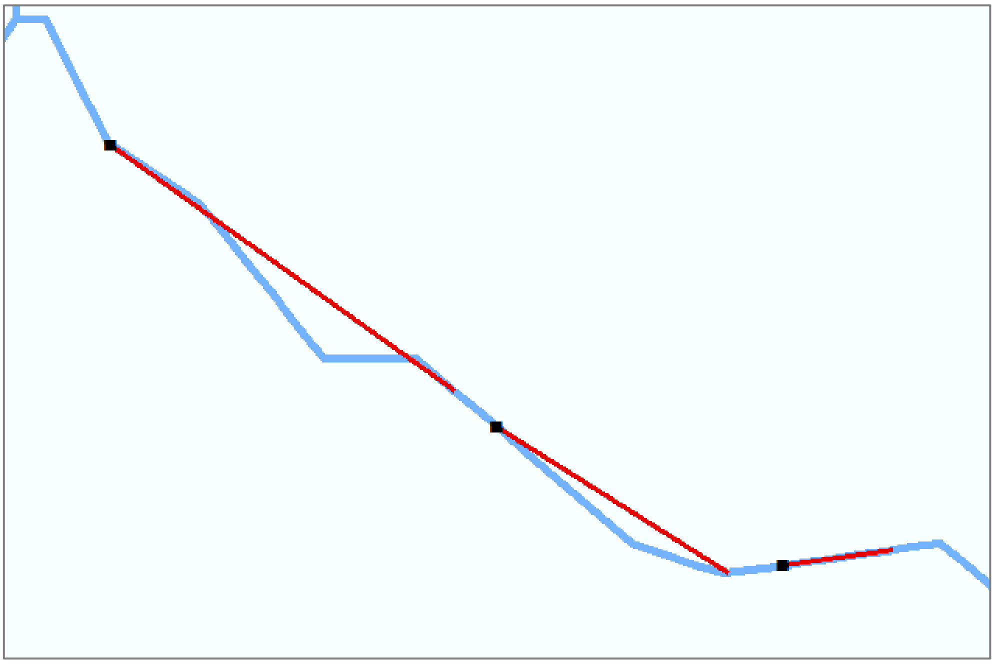

Figure 3: Geographical representation of the river and three identified potential hydro power plants from Figure 2

Figure 3 shows a geographical representation of the three identified potential hydro power projects that were identified in the example from Figure 2. For all the rivers in Georgia, these calculations resulted in 9939 potential projects like these. If we assume that the identified potential power plants were dimensioned in order to be able to utilize all the inflow, they would be able to produce 84 TWh each year (Figure 4).

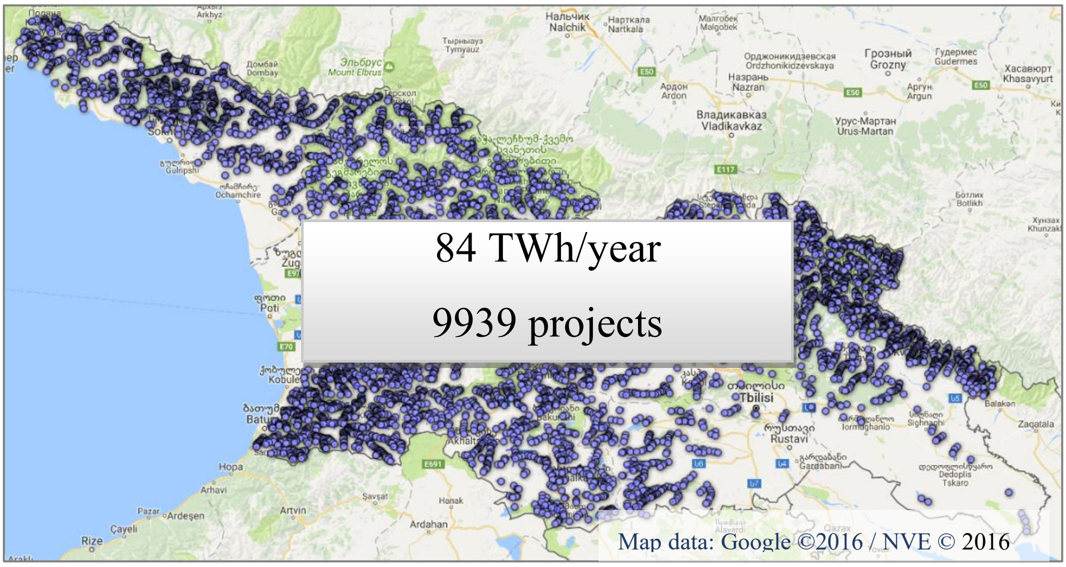

Figure 4: Gross theoretical energy potential in Georgian rivers

1.2 Step 2: Find economically optimal technical dimensions

Step 2: "Which design flow would give the highest potential within a cost limit of 0.35 USD per annually produced kWh?"

Of course, it is not realistic or even possible to develop all the 84 TWh that was identified in Step 1, especially if you take into consideration that the hydro power schemes are supposed to have no regulation capacity. Therefore, in Step 2, the potential was narrowed down by calculating more realistic technical dimensions for all the 9939 potential hydro power plants. The economic feasibility is a matter of construction costs and the flow losses, and this makes the design discharge the dimensioning factor.

According to the Ministry of Energy of Georgia (2016), a specific construction cost of 0.35 USD per annually produced kWh can be considered to be a realistic value for an economical feasible hydro power plant in Georgia. In Step 2, the efficiency losses were excluded from the potential. The product of the gravitation constant and the net efficiency of the hydrpo power plant was assumed to be 8. This ammounts to a presupposed net effeciency of 0,815 for all the mapped projects. This efficiency factor is also assumed to include head losses due to friction in the waterways.

Based on a suggestion from the National Environmental Agency of Georgia, the country was divided into 14 zones, that each was represented by one hydrological series in order to describe the inflow variation.

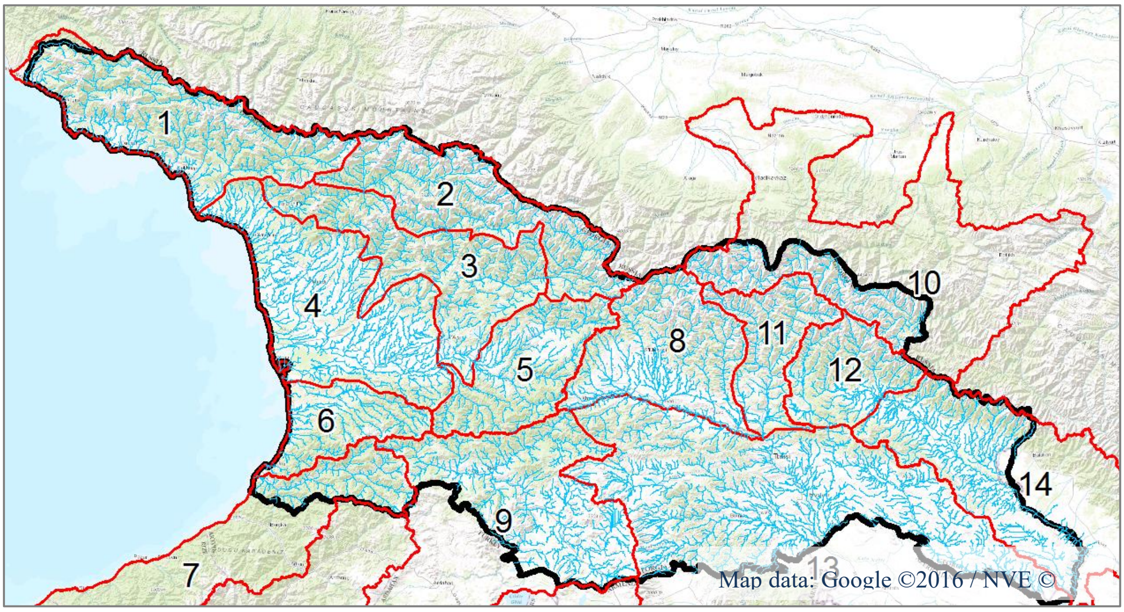

Figure 5: 14 areas, each represented by one runoff series

For each of these 14 zones, the question asked was "If all the identified projects within this area should be designed with the same design flow, which design flow would give the highest potential within a cost limit of 0.35 USD per annually produced kWh?"

To answer this question, we needed a simplified way to investigate the costs for each potential project with different design flows. This was done by creating a cost function based on the *Cost base for small hydro power plants in Georgia*. Of course, a cost function that is supposed to be applied to assess the construction costs for almost 10 000 potential hydro power projects, many bold simplifications had to be done. The assumptions behind the cost function are described in chapter 3.

The cost function was applied in order to calculate the costs for all the projects in each of the 14 areas, for design flows amounting to 1 to 500 per cent of the mean runoff to each hydro power plant. For each area, the design flow was that would result in the biggest hydro power potential to a cost lower than $ 0.35 was chosen as the design parameter for all the hydro power projects in that area. As an example, the results from these calculations for all the mapped hydro power projects in zone 2 are plotted in Figure 6 below.

The difference between specific construction costs and levelized cost of energy

In this analysis, we have used a limit of limit of $0.35/kWh in order to determine design flows and to sort out the most expensive projects. This is refers to the specific construction costs, that is the total construction costs divided by the mean annual hydro power production.

The specific construction costs must not be confused with for instance the levelized cost of energy, that is also widely used to designate the costs of hydro power projects. Levelized cost of energy is defined as the mean net present value of every produced kWh throughout the lifetime of the power plant.

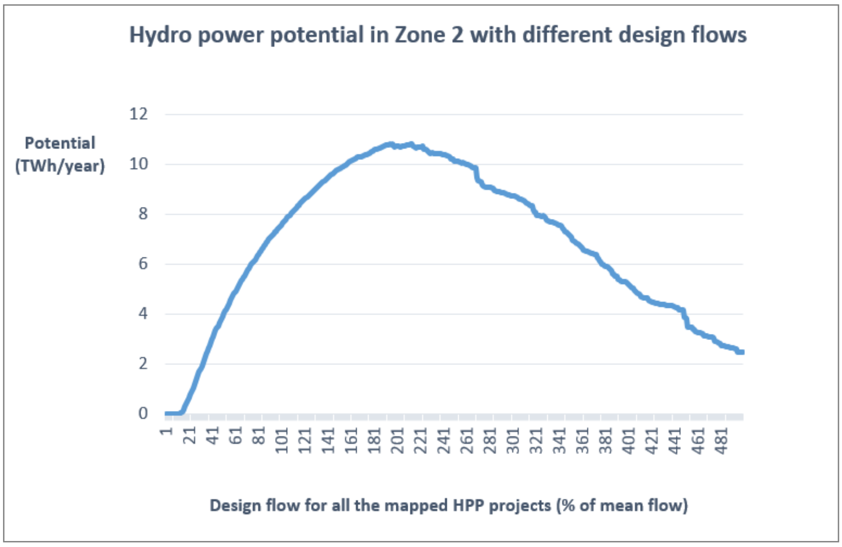

Figure 6: Hydrpo power potential in Zone 2 with different desigd flows for all the mapped hydro power project in this zone

Figure 6 shows, that for the mapped projects in Zone 2, where the inflow variability was represented by the metering station "Kadori – V. Lata", the technical hydro power potential was calculated to be 11,9 TWh/year. This optimum was found when all the mapped hydro power projects were designed with a design flow amounting to 197 % of the mean inflow. Similarly, the design flow for the projects in the 13 other zones were calculated. The design flow for all the 14 zones are given in table 1 together with the total hydro power potential that you will get if all the mapped hydro power projects in the different zones are designed with this design flow. Bear in mind that this potential still includes mapped hydro power potential with a construction cost higher than 0.35 USD per annually produced kWh.

Zone	Station number	Metering station	Design flow (% of mean inflow)	Hydro power potential (TWh/year)
1	37	Kadori - V. Lata	226 %	13,9
2	128	Rioni - C. Oni	197 %	11,9
3	131	Rioni V. Alpana	170 %	7,7
4	231	Texuri - V. Naqlaquevi	173 %	3,1
5	170	Kvirila -C. Sachkere	274 %	1,3
6	242	Supsa - D. Chokhatauri	202 %	2,9
7	278	Achhristskali - D. Qeda	207 %	2,8
8	357	Liakhvi - C. Gori	216 %	1,6
9	326	Faravani - V. Khertvisi	197 %	1,8
10	292	Thusetis-Alazani - V. Shenaqo	209 %	4,0
11	380	Mtiuletis-Aragvi - D. Pas	195 %	2,0
12	438	Alazani - V. Birkiani	213 %	1,2
13	420	Mashavera - D. Kazreti	216 %	1,5
14	440	Alazani - V. Shaqriani	191 %	0,7

Table 1: The metering stations that were selected to represent the inflow variability in each of the 14 areas, the design discharge factor for each area that gives the biggest hydro power potential with a cost lower than $ 0.35 per annually produced kWh and the total technical potential in the area given this design flows

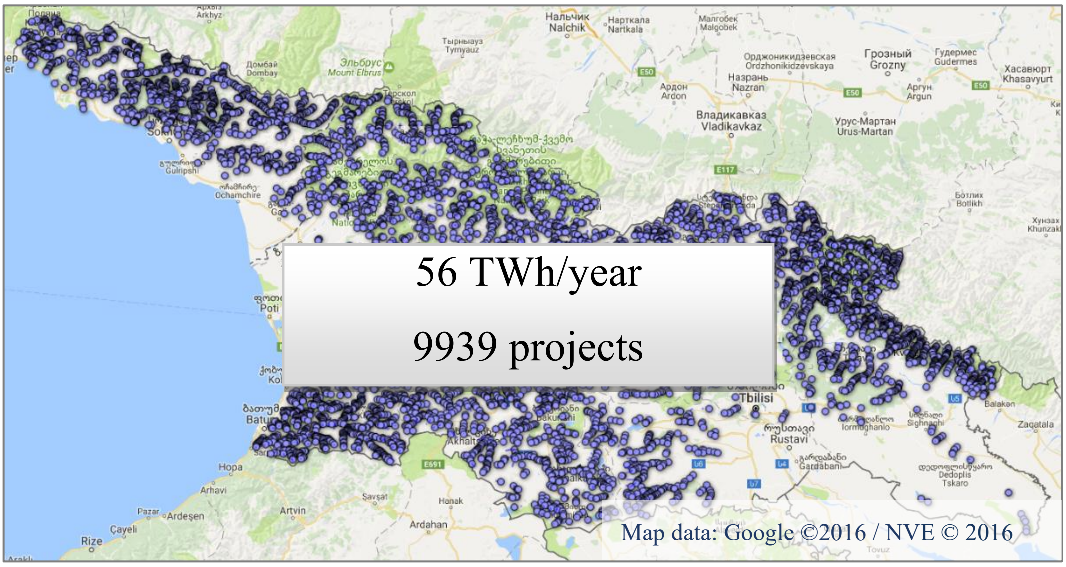

Figure 7: Gross theoretical hydro power potential in Georgia, excluding flow losses, efficiency losses and all potential with a construction cost less than $0.35/kWh. Potential located within protected areas and already developed potential is still included.

1.3 Step 3: Excluding developed and protected potential

The final step of the analysis was to exclude some of the most unrealistic projects. This means to exclude all the projects that are located within protected areas, projects that are already developed and projects with a construction cost lower than 0.35 USD per annually produced kWh.

> ***Step 3: "How much of the hydro power potential is left if we exclude all projects that are located within protected areas, projects that are already developed and projects with a construction cost lower than 0.35 USD/kWh?***

The projects that were already developed were removed manually, based on The Ministry of Energy in Georgia's knowledge and data about the developed hydro power plants in the country. In some instances, there were mapped potential where the catchment areas were partly transferred to other rivers. In such cases, the hydrological input was corrected, and the potential for using the remaining catchment area was calculated.

After these exclusions, the data set was reduced to 2286 potential hydro power plants amounting to 30 TWh.

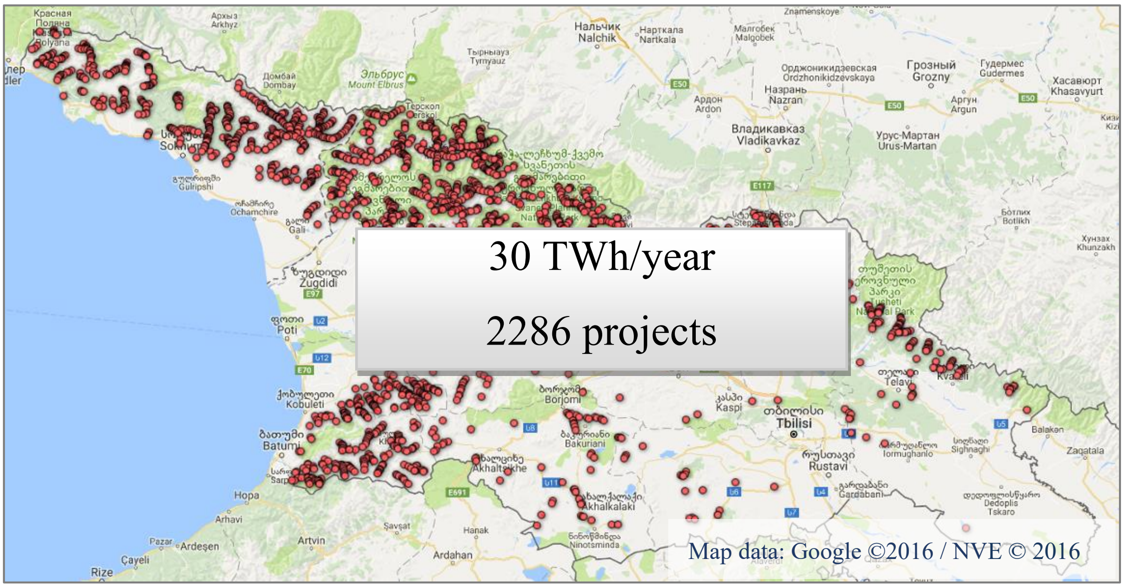

Figure 8: Filtered hydro power potential in Georgia with a construction cost lower than $0.35 per annually produced kWh.

2 Preparing Geographical Data

A geographical elevation model, the national runoff map for Georgia, transmission line maps, road maps and the two cost manuals for small and large hydro power plants served as input data for this analysis.

These datasets, however, had to be prepared and transformed into datasets and that were utilizable for the calculation model.

2.1 River network and inflow grid

The input needed for step 1, as explained in chapter 1.1, is an elevation model and a runoff map covering the whole of Georgia. From these two data sets, the river network with a corresponding profile table was derived.

2.1.1 Elevation model and runoff map

The applied elevation model is the ASTER Global Digital Elevation Model version 002, developed by NASA JPL.

The runoff map of Georgia was developed through the 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. 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 neighbor countries1.

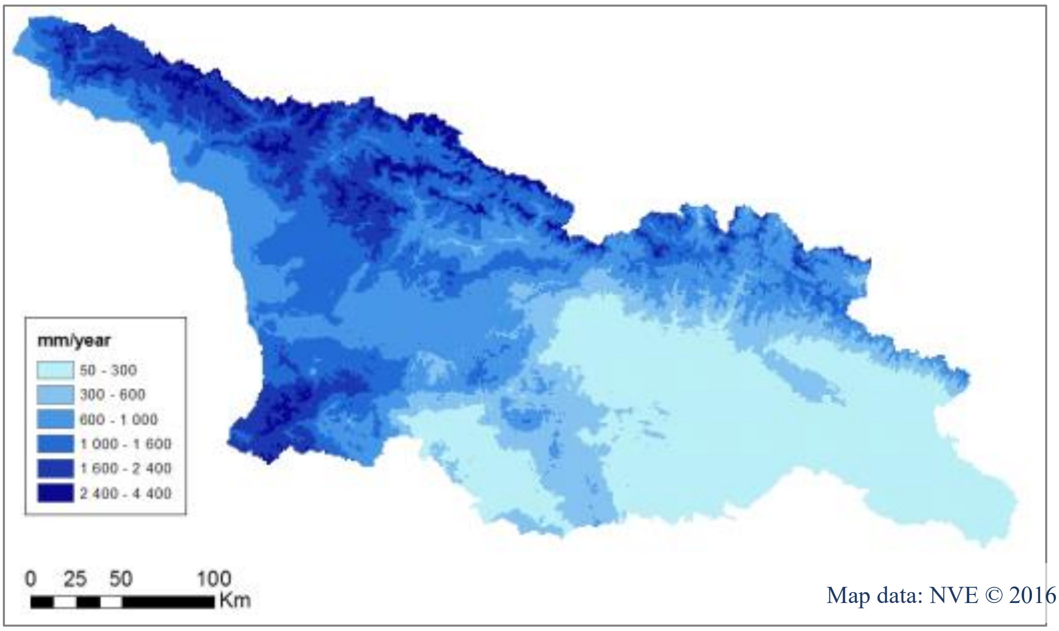

Figure 9: Mean annual runoff (mm/year) for the period 1961-1990 for Georgia and upstream areas in Turkey and Armenia draining to watersheds in Georgia[1]

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[1] Norwegian Water Resources and Energy Directorate, Stein Beldring (ed.) (Report 27, 2017): *Runoff map of Georgia* (http://publikasjoner.nve.no/rapport/2017/rapport2017_27.pdf)

2.1.2 Deriving the three dimensional river network

In Figure 1, “River Network” is listed as input data to the first step of the process, that is the localization of potential projects. This three dimensional river network had to be derived from the elevation model.

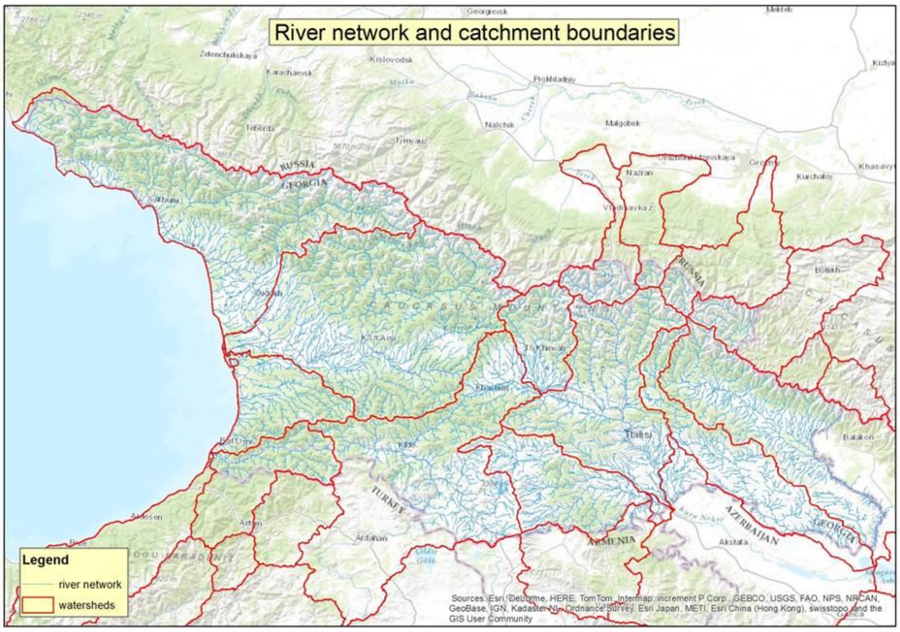

Figure 10: River network and catchment areas

The three dimensional river network was derived from the digital elevation model alone, through the following steps showed in Figure 11.

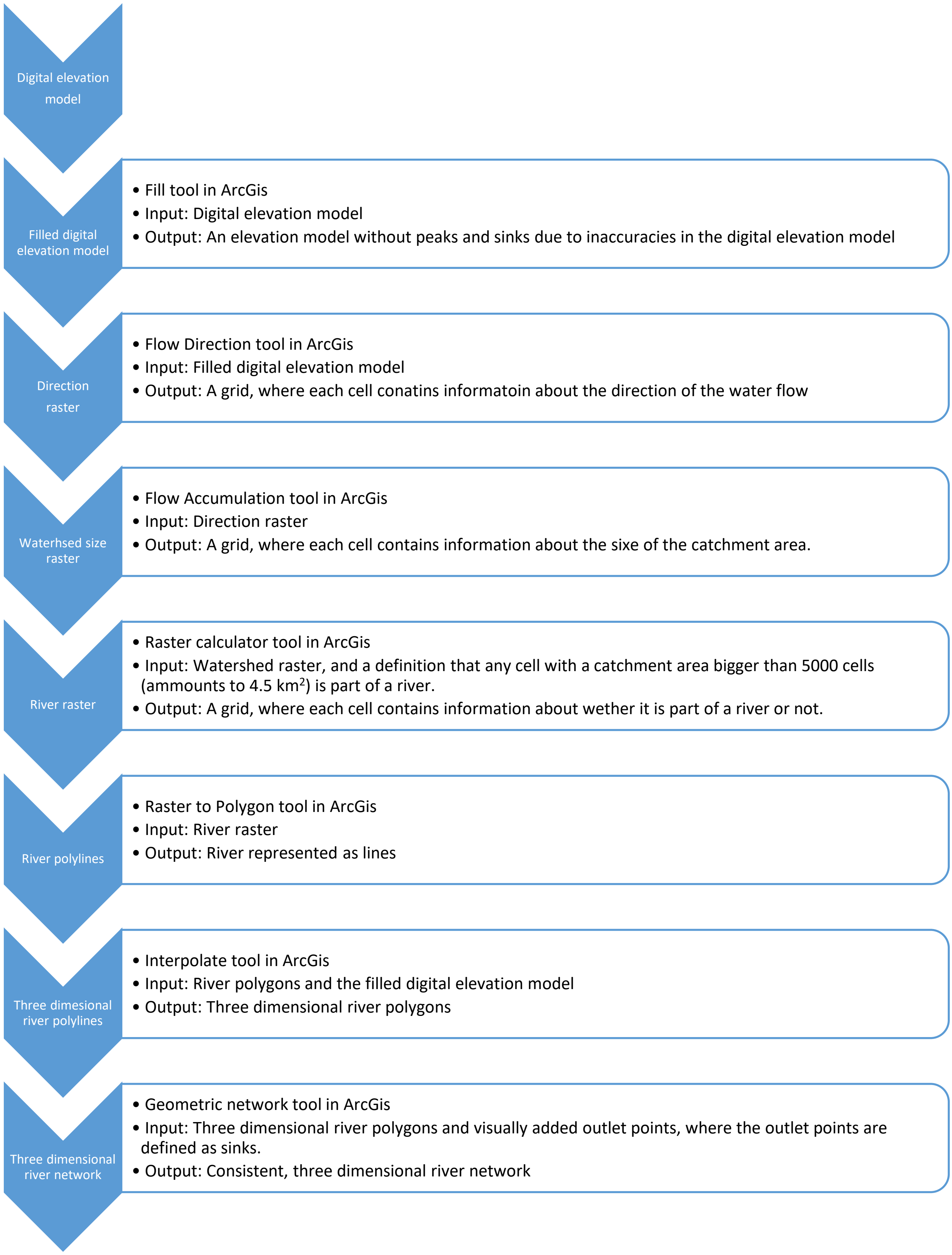

Figure 11: The process of determining a three dimensional river network using ArgGis and the digital elevation model as the only data input.

As shown in figure 11, the first step was to smoothen out the digital elevation model from ASTER. This was needed because small imperfections in the input data. The next step was to use the filled digital elevation model to create a raster with information about the flow direction. This means, that each cell in the grid contains the information about *"If a drop of water flows into this cell, to which cell will the water flow further on?"*. Figure 12 shows how the Flow Accumulation tool in ArcGis. In this tool you use an elevation grid as input, and calculate a new grid with information about the flow direction.[2]

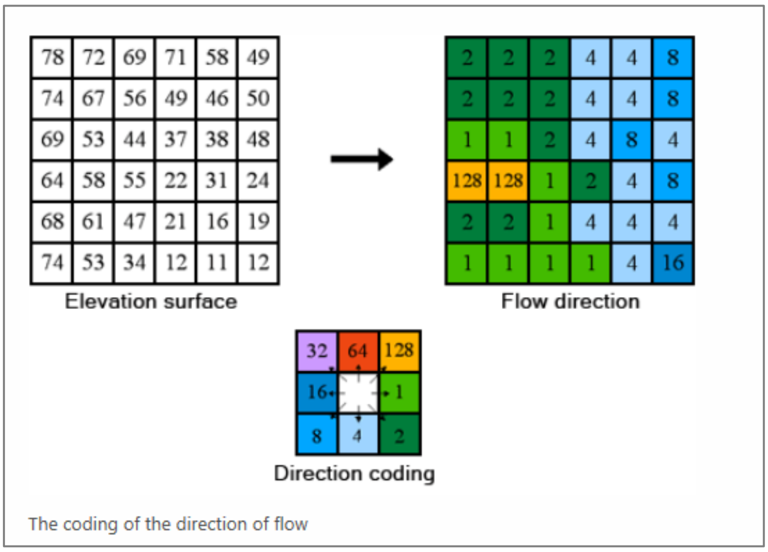

Figure 12: The coding of the direction of flow in ArcGis[2]

The next step was to calculate the watershed size raster. This raster was calculated using the Flow Accumulation tool in ArcGis.[3]

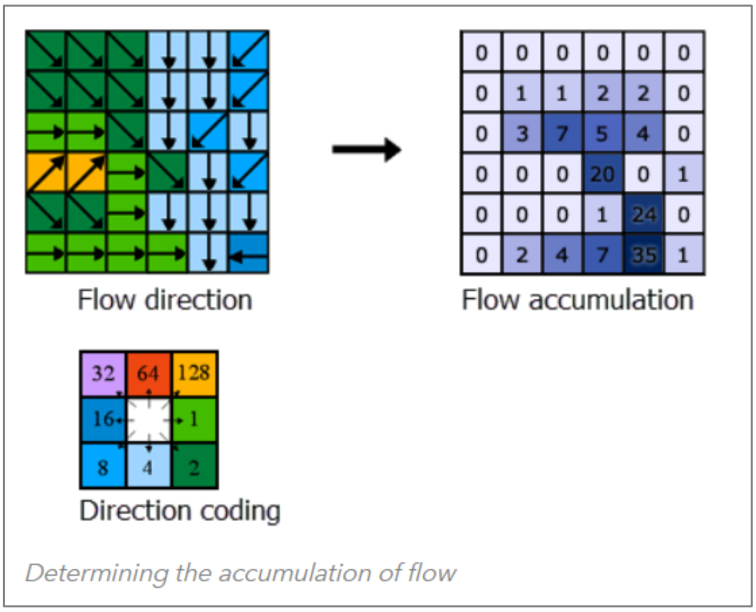

Figure 13: How the flow accumulation is determined in the Flow Accumulation tool in ArcGis[2]

[2] http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/how-flow-direction-works.htm

[3] https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-flow-accumulation-works.htm

In this analysis, we have defined any cell with a catchment area bigger than 4.5 km^2 to be part of a river. This, of course, is a bold assumption that might give too many rivers in dry areas and too few rivers in wetter areas. Still, for the purpose of mapping the hydro power potential, the accuracy is considered to be sufficient.

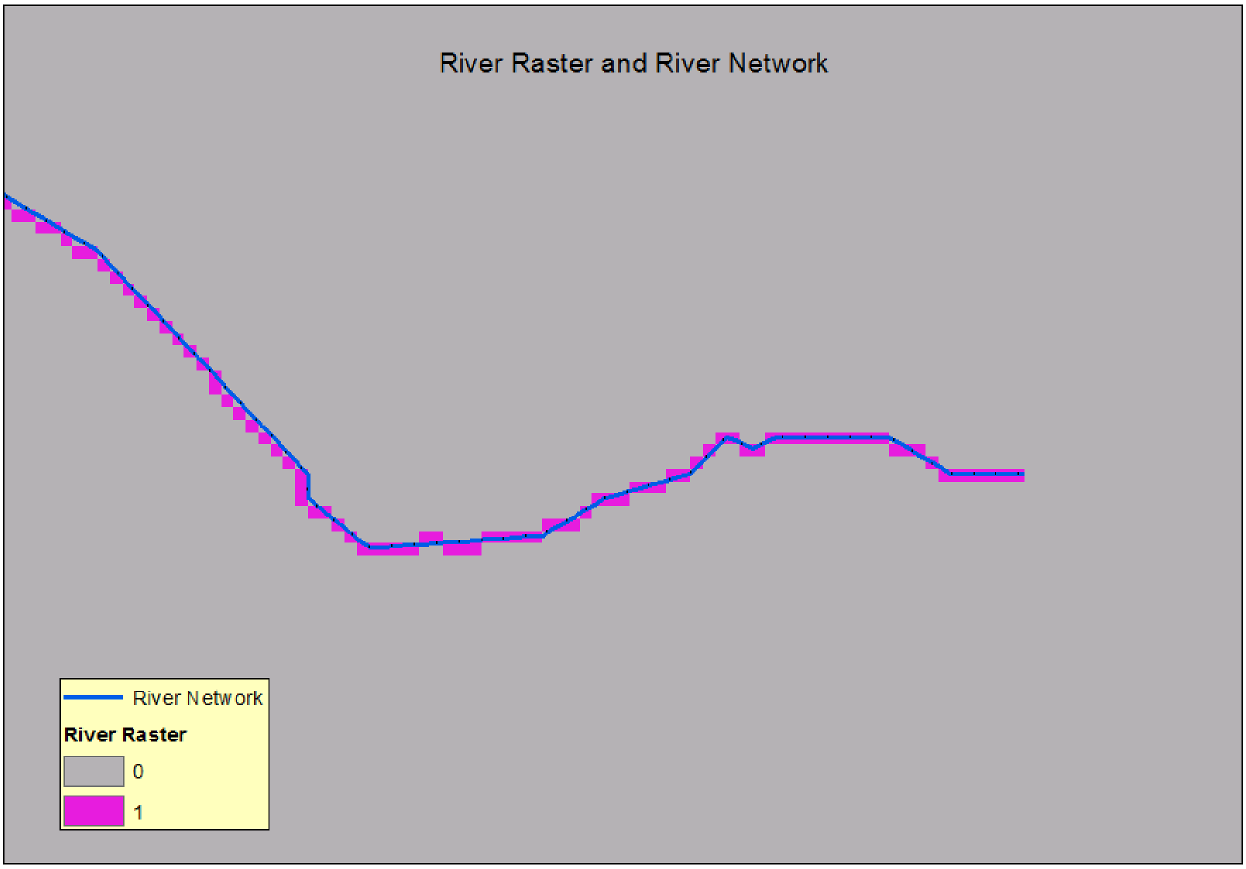

Figure 14: Example of river raster and river network. Cells in the river raster with the value "1" have a catchment area bigger than 4.5 km2, and are defined to be part of a river.

4,5 km^2 amounts to 5000 cells in the watershed size raster. Therefore, the river raster could be calculated by using the Raster Calculator tool in ArcGis. This gave a grid with information about whether each cell is part of a river or not. Subsequently, this gird was used as input to the Raster to Polyline tool in ArcGis in order to create river polylines. Then, the lines had to

be corrected visually in order to make sure that the river is consistent. That means, that from the source to the next lake or to the sea, there should be no loops. These errors had to be corrected visually, and was one of the most time consuming processes in this project. Figure 14 shows a very small extraction of the two datasets that represents the rivers as a grid and as lines.

The next step was to create three dimensional river polylines, that is river lines with added information about the elevation. This was done by applying the Interpolate tool in ArcGis, and data input from the filled elevation model.

The final step was to establish the three dimensional geometrical river network. In order to do this, we had to create outlet points at the river segments that ends in the sea or in a lake. Then, the water flow direction was modelled by connecting all the river segments and outlet points together in a geometric network in ArcGis. This river network, with consistent information about the flow direction of the water, was used as input in the hydro power potential mapping process as described in chapter 1.

The difference between runoff and inflow

The Georgian runoff map contains information about the quantity of water that discharges to the rivers and stream channels, lakes or directly into the ocean, from each square kilometer in Georgia. This includes both surface and subsurface flow of water.

The inflow raster that was needed to map the hydro power potential, contains information about the total inflow, not only from each 30x30 m cell, but from the whole catchment area of each cell.

2.1.3 Inflow raster

In Figure 1, the runoff map is listed as input data to Step 1, "Locate potential projects". Actually, the runoff map only gives the runoff from each point in the river. To be applied in the calculation model, it had to be combined with the elevation model in order to calculate an inflow grid, that contains information about the mean *inflow* to each point in the rivers.

The inflow raster was calculated by using the flow accumulation tool in ArcGis. But instead of calculating how many other cells that flows into each cell, each cells was this time weighted with a value derived from the runoff map, that is, the mean annual runoff from each cell. This gave grids with 30x30 meter resolution with information about the inflow to each cell.

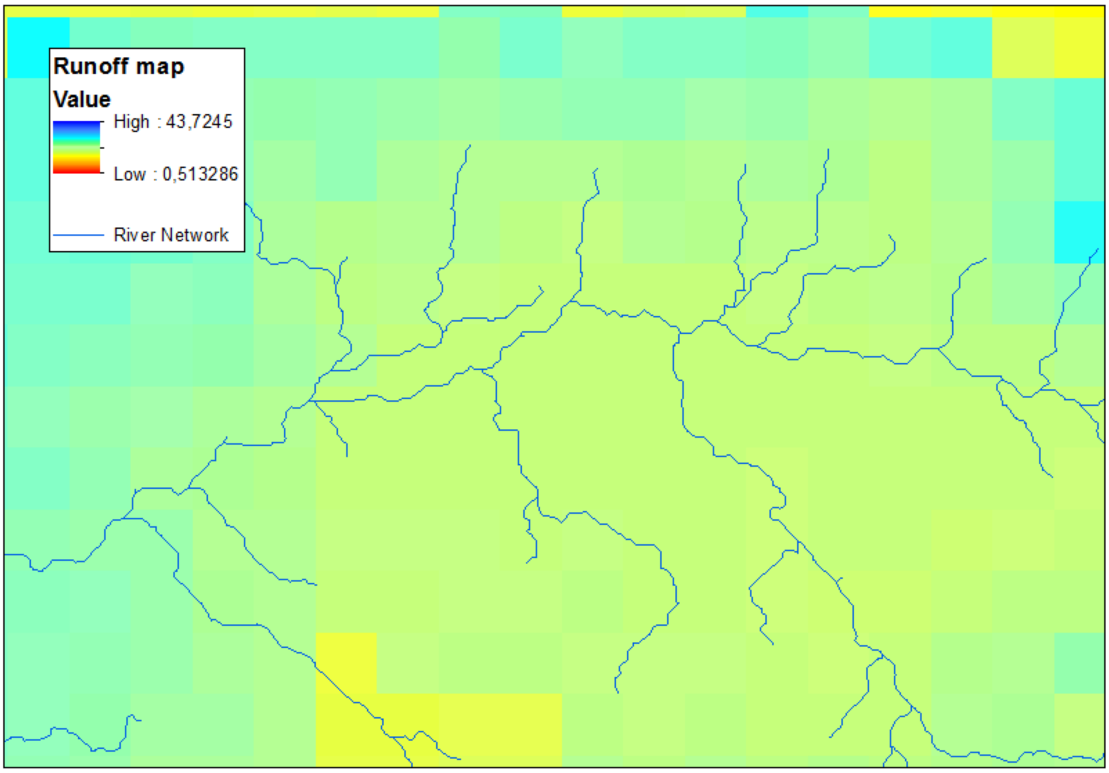

Figure 15: The river network for a part of a Georgian together with the 1x1 km runoff map

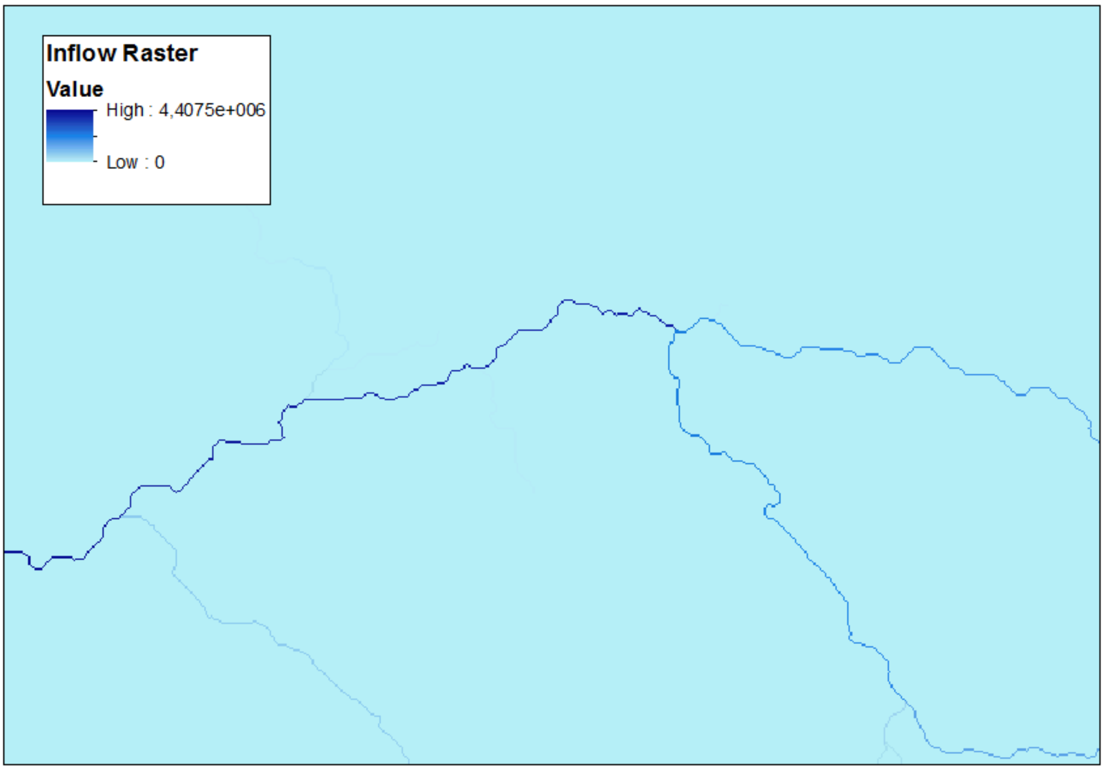

Figure 16: The 30x30 m inflow raster covering the same area as the map in figure 15.

2.2 Roads and transmission grids

The distance to the nearest road was needed for each of the mapped hydro power project in order to calculate the access road costs. The transmission line costs were not calculated, but in the final results, the distance to the nearest existing transmission line is given, as well as the distance to the nearest transmission line according to the master plan for transmission grid development in Georgia.

The Ministry of Energy of Georgia provided maps covering roads, existing transmission grids and transmission grids according to the Georgian transmission line development plan. These data sets were used as input to the Euclidian Distance tool in ArcGis to calculate distance grids.

2.3 Cadaster data

In the final results, the cadastrial code is given for the mapped hydro power projects where these data is available. This code can be used to determine the land ownership, and the data was provided by the Ministry of Justice of Georgia.

3 Cost function

A function has been programmed using Excel VBA, which calculates the total cost of a potential hydropower project based on the input parameters coming from the GIS analysis done by NVE.

The function is based on the "Cost Base for Small Hydropower" and "Cost Base for Hydropower plants" created in cooperation between the Ministry of Energy of Georgia and the Norwegian Water Resources and Energy Directorate (NVE).

The function is a simplified tool in order to get a rough estimate of the cost of a potential project and thereby identify the best projects. Because the number of input values is limited, several assumptions are made in order to calculate the cost. This gives the calculated cost a large margin of error.

3.1 About the assumptions

The cost can be sub-divided into the different components if necessary.

Overall, the same assumptions have been made as for the Norwegian GIS analysis for small hydropower. In Georgia, the geographical premises are different, and these assumptions might not be suitable any more. For instance, there are predominantly high-head, low-flow power plants in Norway, whereas the GIS analysis of Georgia shows that there are many potential low-head, high-flow sites in Georgia.

Only a subset of the cost curves in the cost bases, which contain the most commonly used components have been included in the function.

In order for the function not to throw too many errors, the valid range of most curves has been extended beyond the range specified in the charts. This will decrease the accuracy significantly.

3.2 General

The Excel macro consists of six modules:

- GIS_Georgia_Helper: General constants and helper functions
- GIS_Georgia_Overall: Choosing if large or small hydro, combining separate functions
- GIS_Georgia_Large_Graphs: Functions containing the curves as presented in the cost base. The only changes made is for the valid min-max values of the curves.
- GIS_Georgia_Large_Aggregated: The functions choosing the turbine type etc. It is here all the assumptions are made for large hydropower plants.
- GIS_Georgia_Small_Graphs: Functions containing the curves as presented in the cost base. The only changes made is for the valid min-max values of the curves.
- GIS_Georgia_Small_Aggregated: The functions choosing the turbine type etc. It is here all the assumptions are made for small hydropower plants.

There are explanatory comments inside the functions with references to which chart the function is based on.

3.3 Assumptions for Small Hydropower Projects

3.3.1 Intake

- The following intake dam dimensions are used, based on the max power:

P_{max}[kW]	Average Height [m]	Width [m]
< 100	1	10
≤ 500	2	20
≤ 1000	3	30
≤ 13000	4	30

- A water speed of 1 m/s is used to calculate the surface area of the intake screen.
- For plants with P_{max} < 500 kW no intake gate is used, for larger (up to 13 MW) plants, a sliding gate is used.
- If the average slope of the waterway is more than 50 %, the total cost of the intake is increased by 30 % in because of expensive transport (helicopter etc.).

3.3.2 Electro-Mechanical

- Only a single turbine is used.
- Only the curves for the complete electro-mechanical delivery are used. For P_{max} < 500 kW the ones for micro power plants are used.
- For heads lower than 25 metres, a Kaplan-turbine is used.
- For larger heads, the cost is calculated for both Pelton- and Francis-turbines and the one with the lower cost is chosen.

3.3.3 Waterway

- The diameter of the pipe is calculated by assuming a water speed of 3 m/s.
- For slopes of less than 50 % and diameters less than 2.5 metres:
  - The diagonal length is used ($\sqrt{length^2 + head^2}$).
  - GRP pipes are used. If the head exceeds 320 m, spiral welded steel pipes are used for the section with higher head.
- For slopes of less than 50 % and diameters more than 2.5 metres a diagonal length ($\sqrt{length^2 + head^2}$) tunnel is used.
- For larger slopes a horizontal tunnel and a steep drilled hole is used:
  - The last 20% of the horizontal length is steel pipe in trench.
  - 10 % of the horizontal length is steel pipe in tunnel on foundation blocks.
  - Tunnel length is (horizontal length - half head). Average between good and poor rock quality is used.
  - Drilled hole length is diagonal between h and h/2. Medium rock quality is used.

3.3.4 Power Station

- A surface power station is assumed for all power plants.

3.4 Assumptions for Large Hydropower Projects

3.4.1 Intake

- The intake/dam cost is calculated in the same function as the penstock.
- For heads below 32.5 metres, the cost is assumed to be 1 million USD (very rough estimate).
- For larger, the cost is assumed to be 0.8 million USD (very rough estimate).

3.4.2 Electro-Mechanical

- Only a single turbine is used, because most plants identified in the analysis are below 40 MW
- If the head is lower than 32.5 metres a Kaplan-turbine is used.
- For larger heads, the cost is calculated for both Pelton- and Francis-turbines and the one with the lower cost is chosen.
- For the electro-technical components the rpm of the turbine and generator is estimated from the discharge

Q_{max}[m^3/s]	rpm
< 6	750
≤ 30	500
≤ 80	300
≤ 130	200
> 130	100

3.4.3 Waterway

- The diameter of the pipe is calculated by assuming a water velocity of 3 m/s.
- For heads of less than 32.5 metres, no penstock is used. It is assumed that the power station is located together with the dam and inlet.
- For larger heads with slopes of less than 1/6 (17 %) a tunnel with the diagonal length is used. The last 75 metres have steel lining.
- For larger heads with slopes of more than 1/6 (17 %) a tunnel with the diagonal length is used.
  - Tunnel length is (horizontal length - half head). Medium rock quality is used.
  - Drilled hole length is diagonal between h and h/2. Medium rock quality is used.
  - The last 75 metres of pipe have steel lining

3.4.4 Power Station

- For heads of less than 32.5 metres, a surface station is used.
- For heads of more than 32.5 metres, an underground power station is used. A 300 m access tunnel is added to the cost.

3.5 Assumptions for all hydropower plants

3.5.1 Road works

- A road at 30 USD/m is calculated from the nearest road to the power plant.
- A temporary road at 15 USD/m is calculated along the waterway if this one is not in a tunnel.

3.5.2 Land costs and compensatory measures

- Land costs and compensatory measures are not considered

3.5.3 Financial costs

- Costs for servicing a loan during the construction period is added at a rate of 6 % per annum. Construction time is assumed to be 8, 12 or 30 months for plants < 1000 MW, < 13000 MW and ≥ 13000 MW respectively.

4 Results

4.1 Hydro power potential in different regions

Figure 17 and table 2 shows the hydro power potential in the different regions in Georgia. Both the filtered potential with a construction cost lower than $0.35/kW and the gross theoretical hydro power potential is visualized.

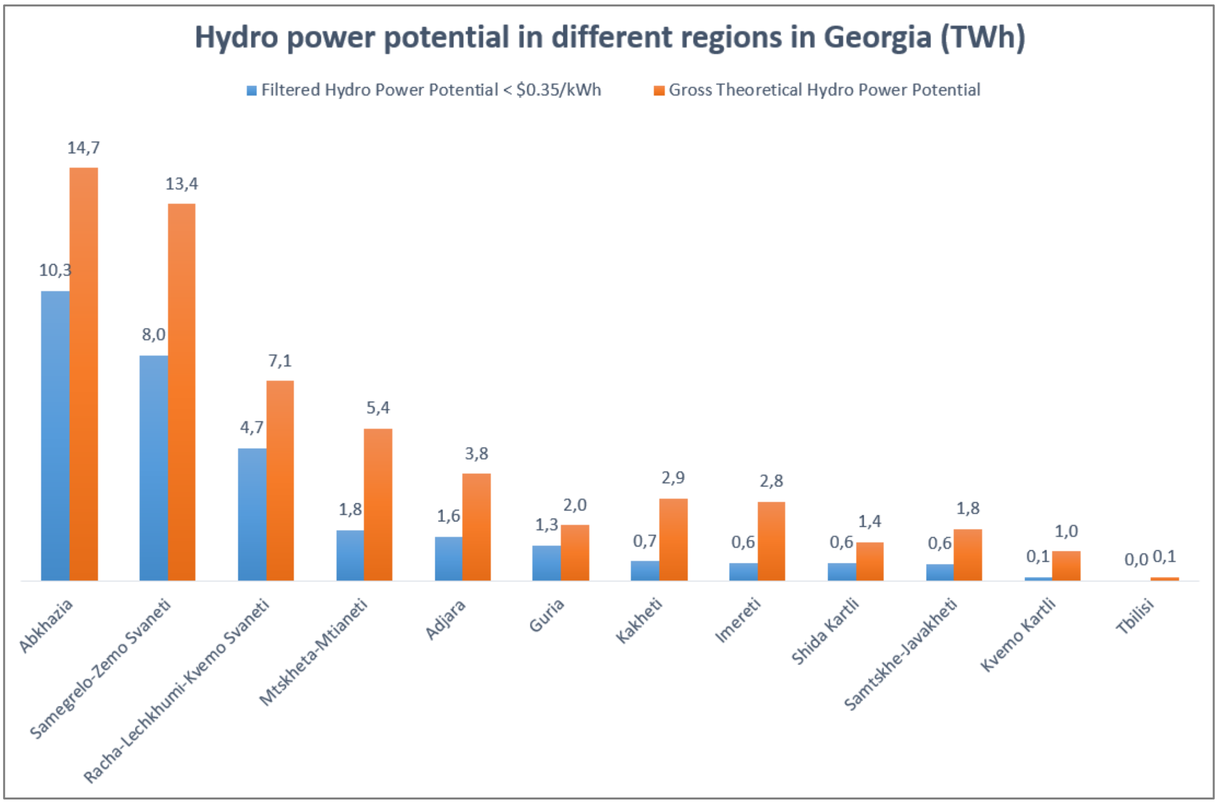

Figure 17: Theoretical hydro power potential in different regions in Georgia

Table 2: The Hydro Power Potential in Different Regions in Georgia

	Filtered Hydro Power Potential < $0.35/kWh		**Gross Theoretical Hydro Power Potential**	
Region	*Mean annual power production (TWh)*	*Number of projects*	*Mean annual power production (TWh)*	*Number of projects*
Abkhazia	10,3	538	14,7	1453
Samegrelo-Zemo Svaneti	8,0	494	13,4	866
Racha-Lechkhumi-Kvemo Svaneti	4,7	405	7,1	1083
Mtskheta-Mtianeti	1,8	184	5,4	1249
Adjara	1,6	204	3,8	827
Guria	1,3	117	2,0	383
Kakheti	0,7	106	2,9	1207
Imereti	0,6	66	2,8	707
Shida Kartli	0,6	88	1,4	695
Samtskhe-Javakheti	0,6	63	1,8	1038
Kvemo Kartli	0,1	21	1,0	418
Tbilisi	0,0	0	0,1	13
Sum	30,4	**2286**	56,5	9939

4.2 Hydro power potential maps

Below, maps with hydro power potential in different regions in Georgia. The data set that is visualized in these maps, is the data set called *Filtered HPP Potential < $0.35/kWh* in the interactive map available at The Ministry of Energy of Georgia's website. This potential excludes potential that is located within protected areas as well as potential that is already developed.

4.2.1 Abkhazia

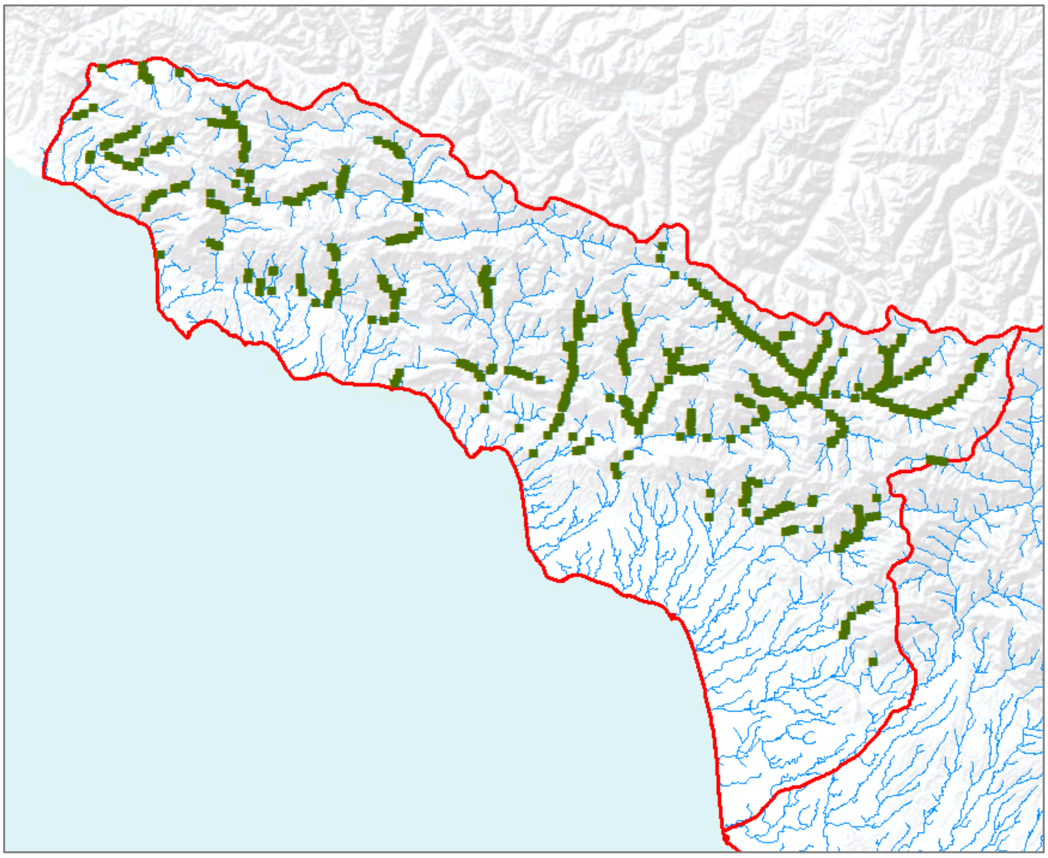

Figure 18: Potential hydro power projects in Abkhazia with a construction cost lower than $0.35/kWh: 538 projects amounting to 10.3 TWh

4.2.2 Samegrelo-Zemo Svaneti

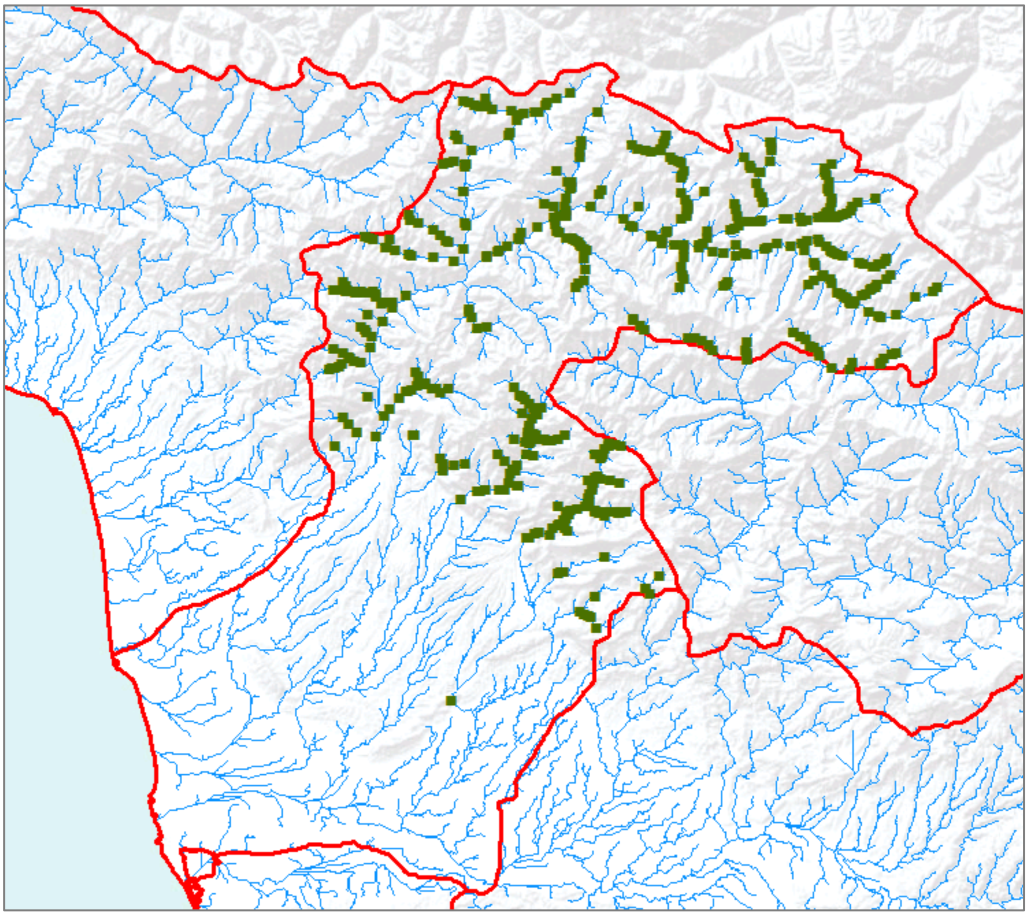

Figure 19: Potential hydro power projects in Samegrelo-Zemo Svaneti with a construction cost lower than $0.35/kWh: 494 projects amounting to 8.0 TWh

4.2.3 Racha-Lechkhumi-Kvemo Svaneti

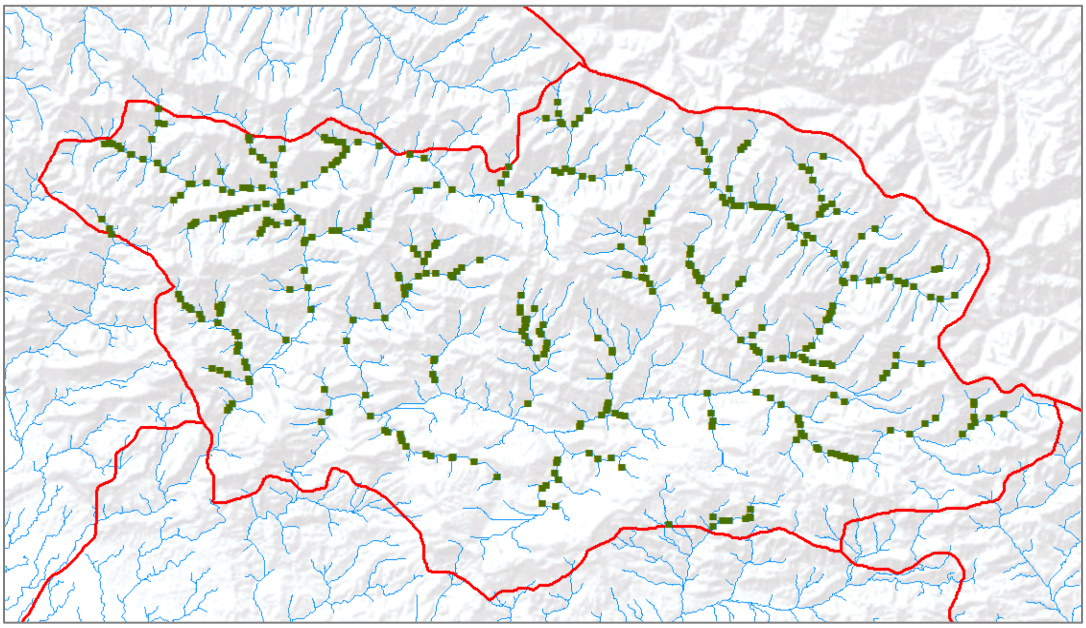

Figure 20: Potential hydro power projects in Racha-Lechkhumi-Kvemo-Svaneti with a construction cost lower than $0.35/kWh: 405 projects amounting to 4.7 TWh

4.2.4 Imereti

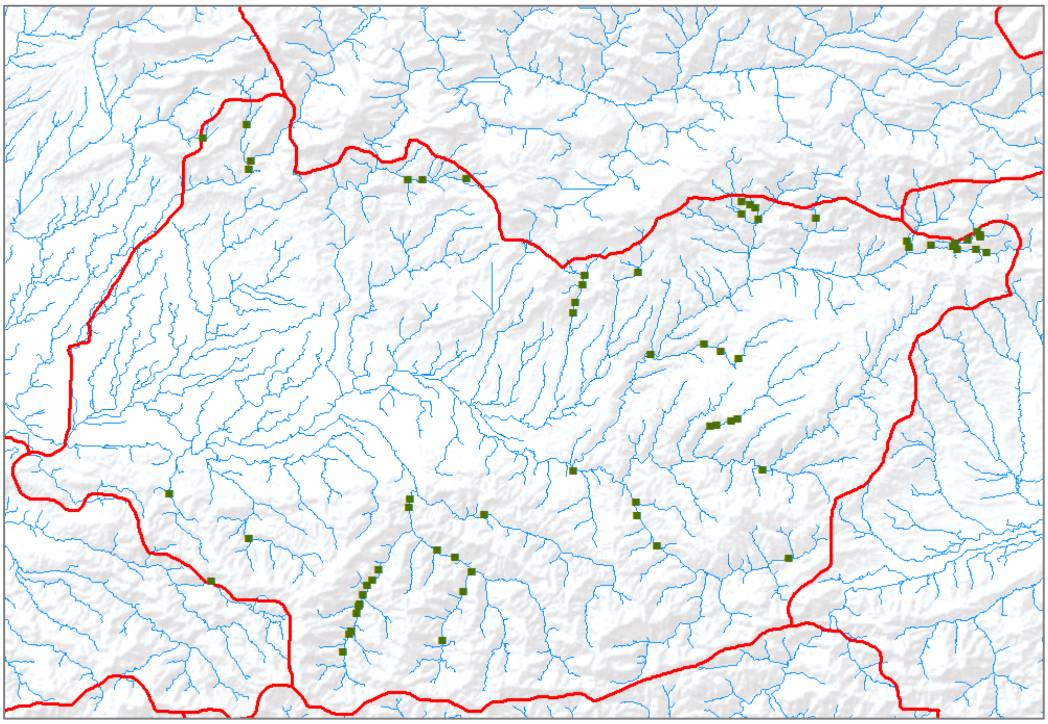

Figure 21: Potential hydro power projects in Imereti with a construction cost lower than $0.35/kWh: 66 projects amounting to 0.6 TWh

4.2.5 Guria

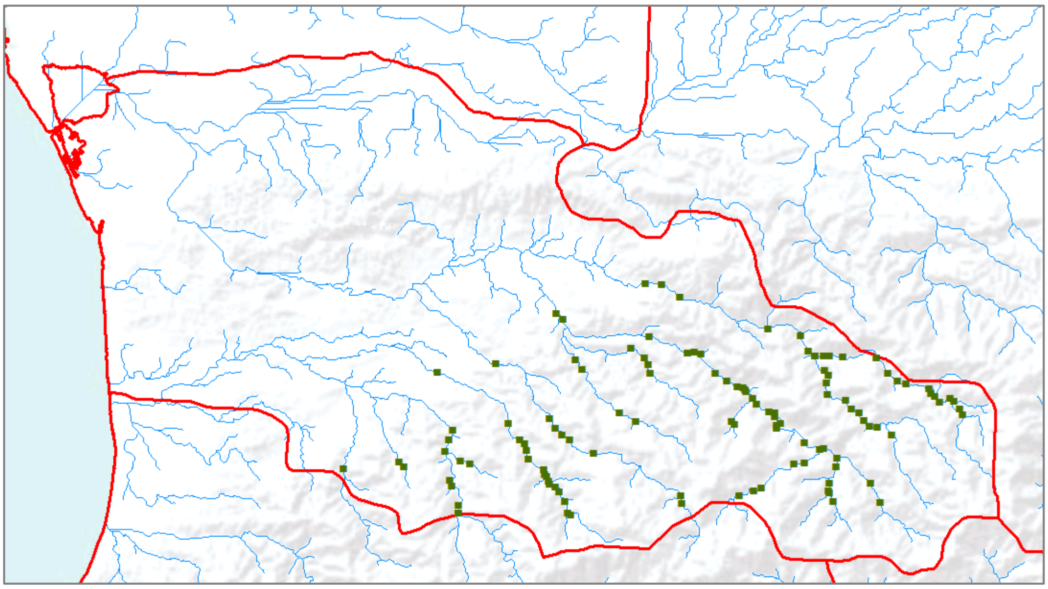

Figure 22: Potential hydro power projects in Guria with a construction cost lower than $0.35/kWh: 117 projects amounting to 1.3 TWh

4.2.6 Adjara

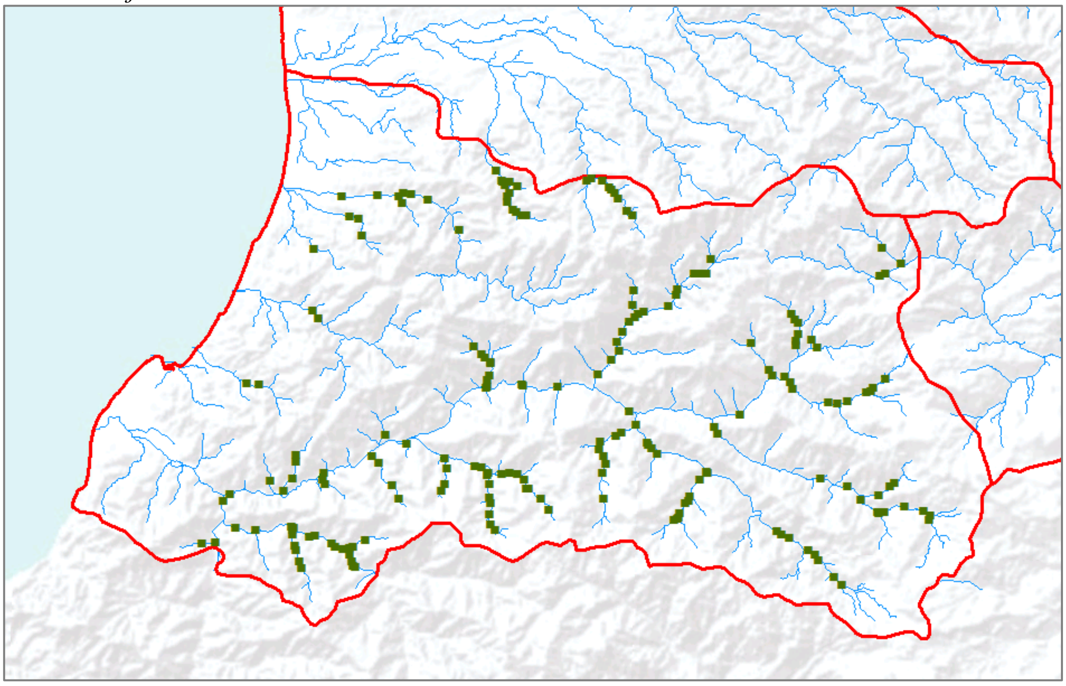

Figure 23: Potential hydro power projects in Adjara with a construction cost lower than $0.35/kWh: 204 projects amounting to 1.6 TWh

4.2.7 Samtskhe-Javakheti

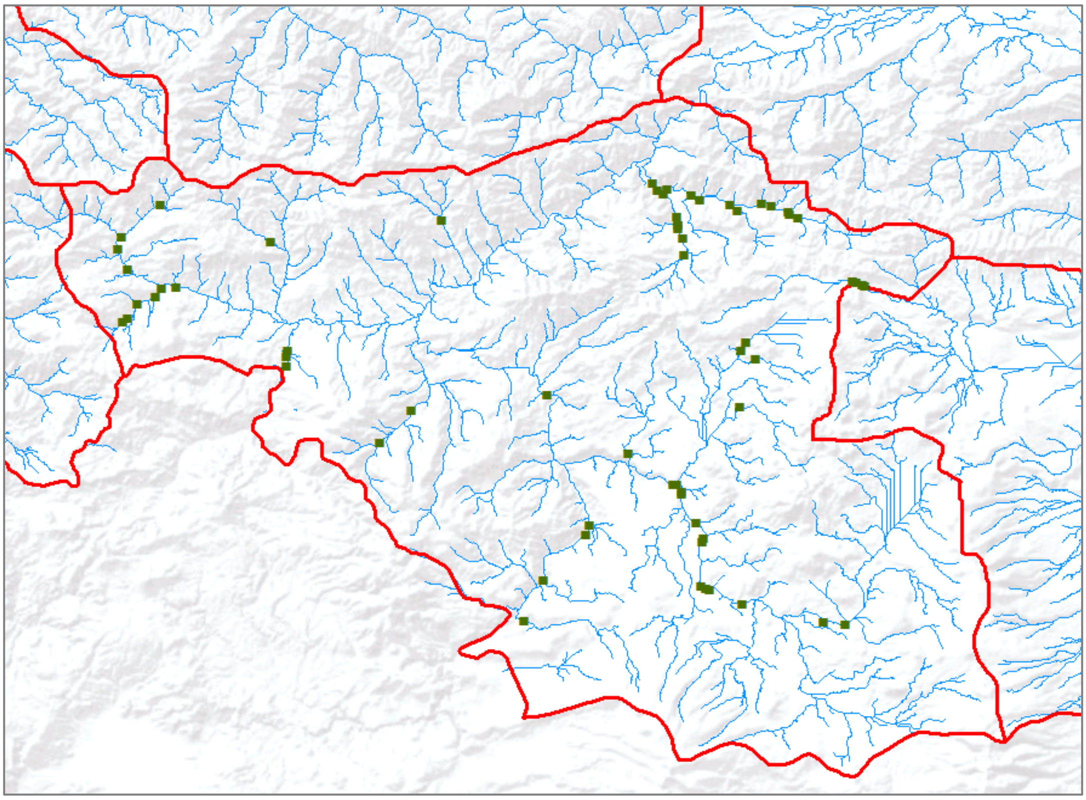

Figure 24: Potential hydro power projects in Samtskhe-Javakheti with a construction cost lower than $0.35/kWh: 63 projects amounting to 0.6 TWh

4.2.8 Shida Kartli

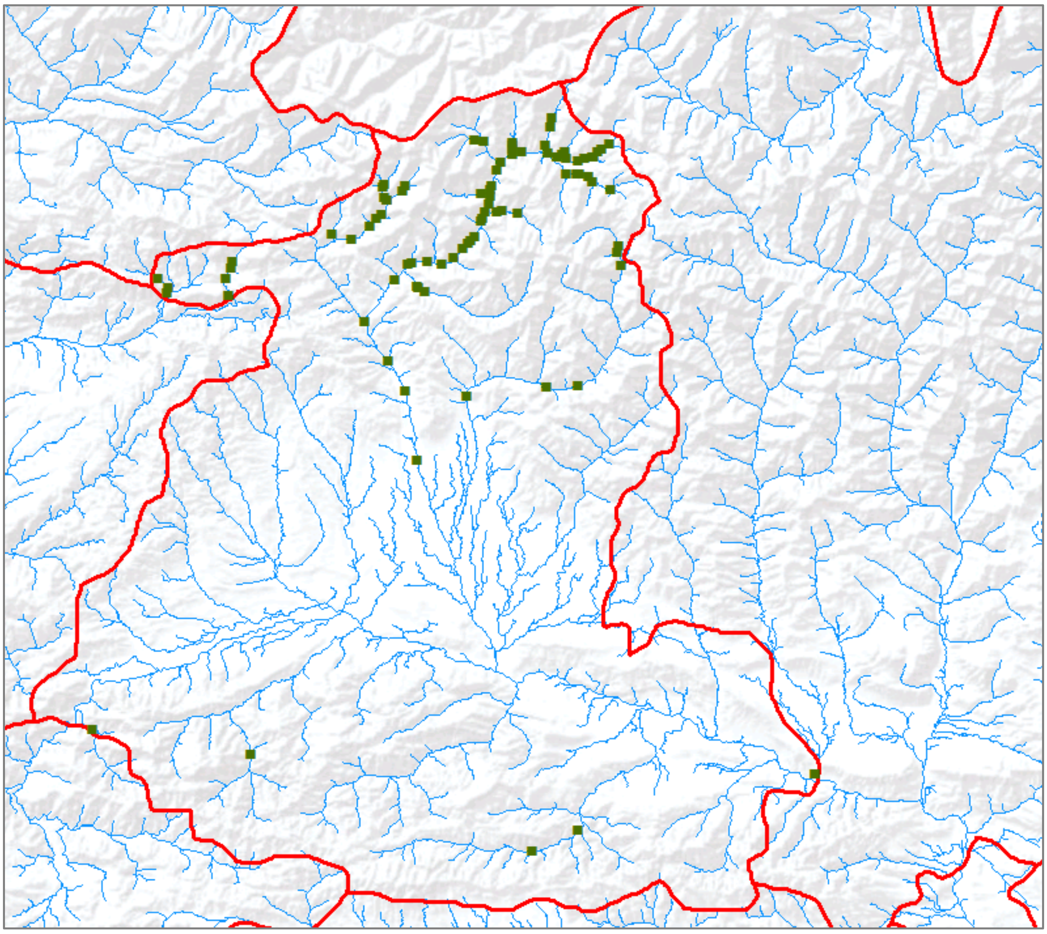

Figure 25: Potential hydro power projects in Shida Kartli with a construction cost lower than $0.35/kWh: 88 projects amounting to 0.6 TWh

4.2.9 Kvemo Kartli

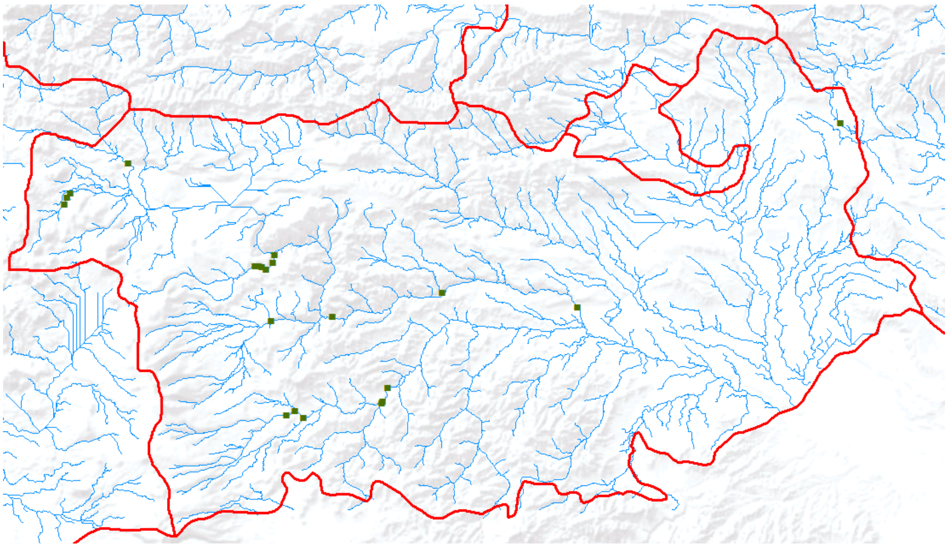

Figure 26: Potential hydro power projects in Kvemo Kartli with a construction cost lower than $0.35/kWh: 21 projects amounting to 0.1 TWh

4.2.10 Mtskheta-Mtianeti

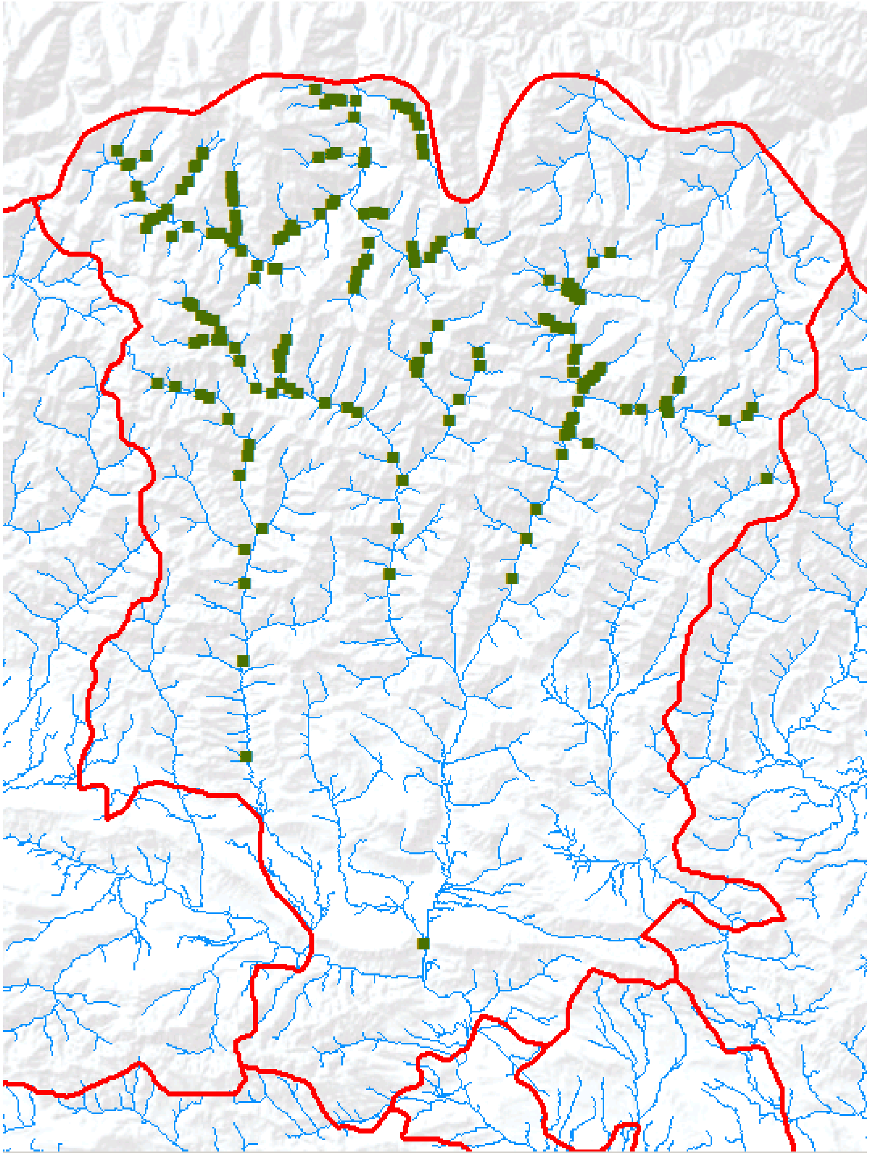

Figure 27: Potential hydro power projects in Mtskheta-Mtianeti with a construction cost lower than $0.35/kWh: 184 projects amounting to 1.8 TWh

4.2.11 Kakheti

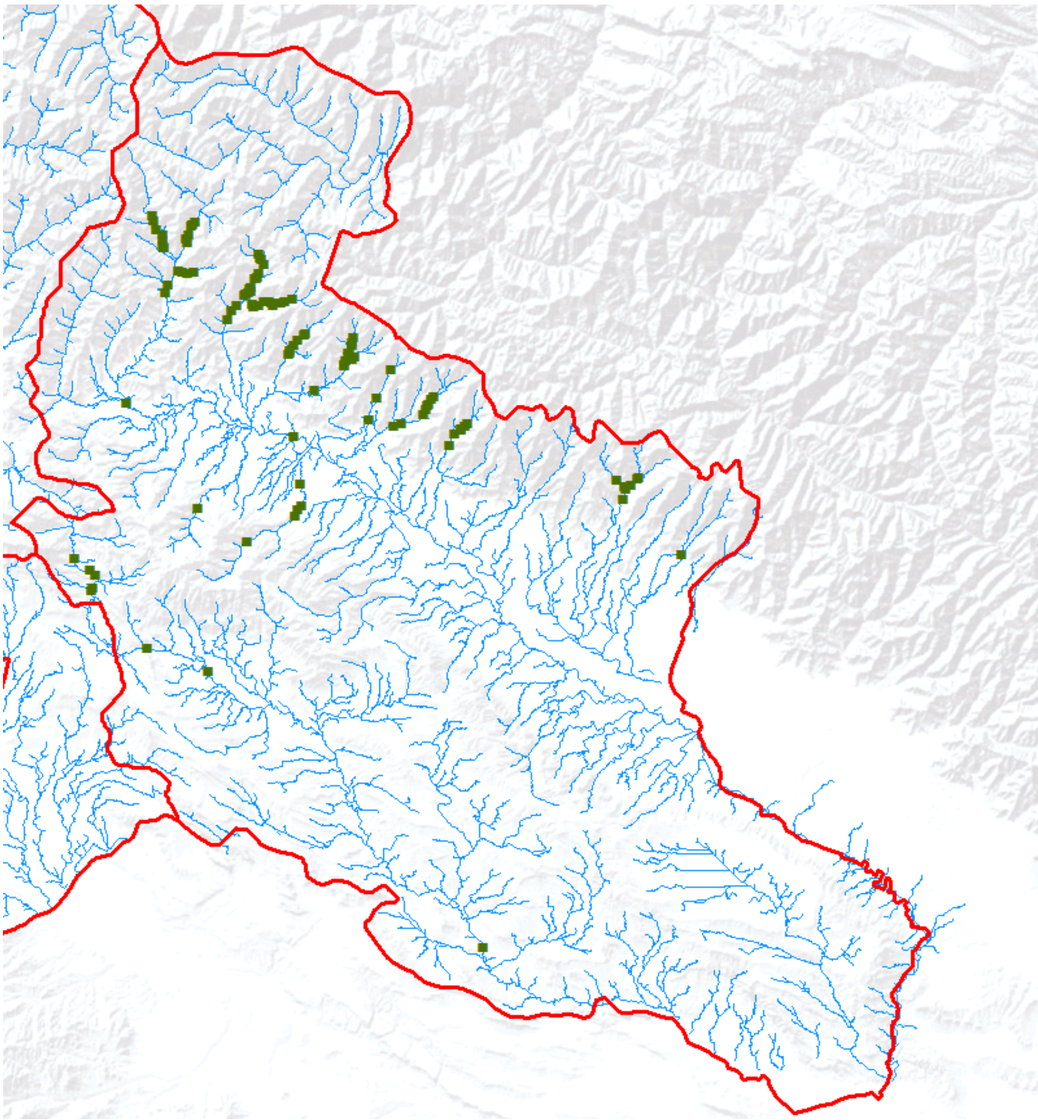

Figure 28: Potential hydro power projects in Kakheti with a construction cost lower than $0.35/kWh: 106 projects amounting to 0.7 TWh

References

Norwegian Water Resource and Energy Directorate and Ministry of Energy of Georgia (2016): *Cost base for small hydro power plants in Georgia*

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Norwegian Water Resources and Energy Directorate, Torodd Jensen (ed.) (Rapport 19, 2004): *Beregning av potensial for små vannkraftverk i Norge*

NVE

Norges vassdrags- og energidirektorat

MIDDELTHUNS GATE 29
POSTBOKS 5091 MAJORSTUEN
0301 OSLO
TELEFON: (+47) 22 95 95 95

www.nve.no