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ARAGVI RIVER BASIN HYDROLOGICAL MONITORING INFRASTRUCTURE ASSESSMENT

USAID GOVERNING FOR GROWTH (G4G) IN GEORGIA

1 SEPTEMBER 2016

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ACRONYMS

G4G	Governing for Growth in Georgia
USAID	United States Agency for International Development
MENRP	Ministry of Environment and Natural Resources Protection
WAP	Water Allocation Plan
WMO	World Meteorological Organization
NEA	National Environmental Agency
GWP	Georgian Water and Power
GSE	Georgian Electricity System
ISO	International Organization for Standardization
ADFM	Acoustic Doppler Flow Measuring
SSC	Suspended sediment concentration
Km	Kilometer
HPP	Hydropower Plant
m	Meter

CONTENTS

1. EXECUTIVE SUMMARY

The fundamentals of water allocation is that any form of abstraction, transfer, storage or other influences on natural stream has effects on the entire downstream river system (CAP-NET 2008).

For surface water allocation, the water users in the nearest future will apply for a permit, which will set their allocation and the conditions under which they can take water. Those wanting to carry out economic activities on a water body may need to apply for a permit.

For the Ministry of Environment and Natural Resources Protection (MENRP) to be able to issue the above said permit and begin development of water allocation plans (WAP), it must have comprehensive information of the entire river basin including the associated groundwater and how it affects the livelihoods and economic activities in the basin and vice versa. Accurate information on river flow and its components is important for analyzing the effects of human activities on river systems, including water pollution, hydraulic construction, water quality distribution and forecast, river resource management, flood estimation and flood damage prevention[1].

In order to have accurate data, MENRP must carry out a continuous analysis where the existence of the updated, real time and reliable hydrological data is a cornerstone in the process of water resource management.

United States Agency for International Development (USAID) project, Governing for Growth (G4G) in Georgia, has been working on the water and energy sector in Georgia since August 2014. This report provides the recommendation for the development and implementation of the minimum network of streamflow gauging stations in the boundaries of Aragvi River Basin which will enable provision of accurate data required to:

- Determine water availability upstream and downstream of Jinvali Dam;
- Develop a water allocation plan and facilitate the process of permitting the surface water abstractions;
- Monitor or manage reservoir water level and releases for water supply, irrigation, hydropower, environmental purposes;
- Protect stream ecology and other instream uses; and
- Plan for a sustainable water future.

The recommendations provided in the report include the number, proposed locations, and type of streamflow gauging stations determined on the basis of recommendations and requirements (criteria) prescribed in World Meteorological Organization (WMO) Manual on Stream Gauging Volume 1 Fieldwork.

The Google Earth application, which can provide images taken at different time periods, elevation indicators, as well as other parameters such as GIS data (Longitude and Altitude), and publicly available Soviet Military maps has been used to determine the compliance of proposed locations for gauging stations using the criteria prescribed in the WMO manual for the selection of the streamflow gauging site locations[2].

The first two site specific locations, Gauging 1 and Gauging 2, are proposed for the reservoir and the area immediately after the tailrace of the Jinvaly Hydro-power plant (HPP). Water level in the reservoir will provide real time information on water stored in the reservoir, i.e. amount of water available to be released for environmental flow, irrigation, industrial and electricity production purposes, while measuring the stage right after the Jinvali HPP tailrace will provide real time information on flood events and water available for the downstream Jinvali dam located water users and environment.

[1] Research article Hydrological Science Journal Volume 57, 2012 - Issue 8

[2] WMO Manual on Stream Gauging Volume 1 Fieldwork

With the consideration of catchment area being 1600 km^2, forming the streamflow together with the discharge of Jinvali Dam downstream, and due to the noncompliance of the morphological and streamflow parameters of the Aragvi downstream to the criteria prescribed in WMO manual for specific site of gauging selection, for the purposes to have complete data on water availability in the river two additional site locations have been determined on the Mtkvari.

On one hand, Gauging 3 proposed location upstream the confluence of the Aragvi and Mtkvari and Gauging 4 downstream of the confluence are far enough upstream from the confluence with another stream or from tidal effect to avoid any variable influence the other stream or the tide may have on the stage at the gauge site. On the other hand, the difference between the streamflow measured at Gauging 4 and Gauging 3 will enable the calculation of streamflow at the outlet of the Aragvi with low uncertainty.

2. BACKGROUND

The lack of hydrological information will make difficult to develop or follow WAP, which proposes to ensure that the needs of the environment are taken into account when determining how much water is made available for consumptive purposes (licensed and non-licensed).

The hydrological data, like precipitation data, runoff data, groundwater table data, etc., should be gathered and stored throughout the years by monitoring gauging stations of a network. Current conditions of the observation network is that the number of meteorological and streamflow gauging stations are several times less compared to the number of stations active during the Soviet period.

In case of the observation network for Aragvi River Basin, the number of active stream flow gauging stations is reduced from 14 to 3 located upstream of Jinvali Dam. Moreover, current spatial dissemination of active stations can't ensure the provision of complete information to MENRP on stream flow discharge below the Jinvali Dam where the greater part of water abstraction is in existence.

Jinvali Reservoir can store approximately 1/3 of Aragvi's annual runoff and can have a greater impact on water availability downstream the dam, whilst neither the MENRP nor National Environmental Agency (NEA) mandatory provision of real-time or historical information on water level of reservoir is yet available.

In the environment of non-existence of water management rules and authority, utilities and more specifically Georgian Water and Power (GWP) is operating the Jinvali Dam driven by the operational plan of Georgian State Electrosystem (GSE) and water supply systems on a day-to-day and seasonal basis with obligation of developing operating strategies to meet their own objectives and somehow maintain the ecological function of rivers. At the same time, they must serve multiple water needs, i.e share available water for recreation, cities, farms, energy production, and industries located downstream, which remains subject to negotiation between GWP and water users downstream.

The use of streamflow information affects every citizen's life in number of different ways. Reliable streamflow information is needed for many purposes including: Flood warnings and forecasts; drinking water management; irrigation withdrawals; hydroelectric power production; wastewater discharges and reservoir releases; legal and treaty obligations on international waters; preservation of aquatic habitats; water quality standards; recreation; infrastructure designs for highways, bridges, culverts, dams, and levees; and for scientific investigations of streamflow history, ecosystem health, and climate change.

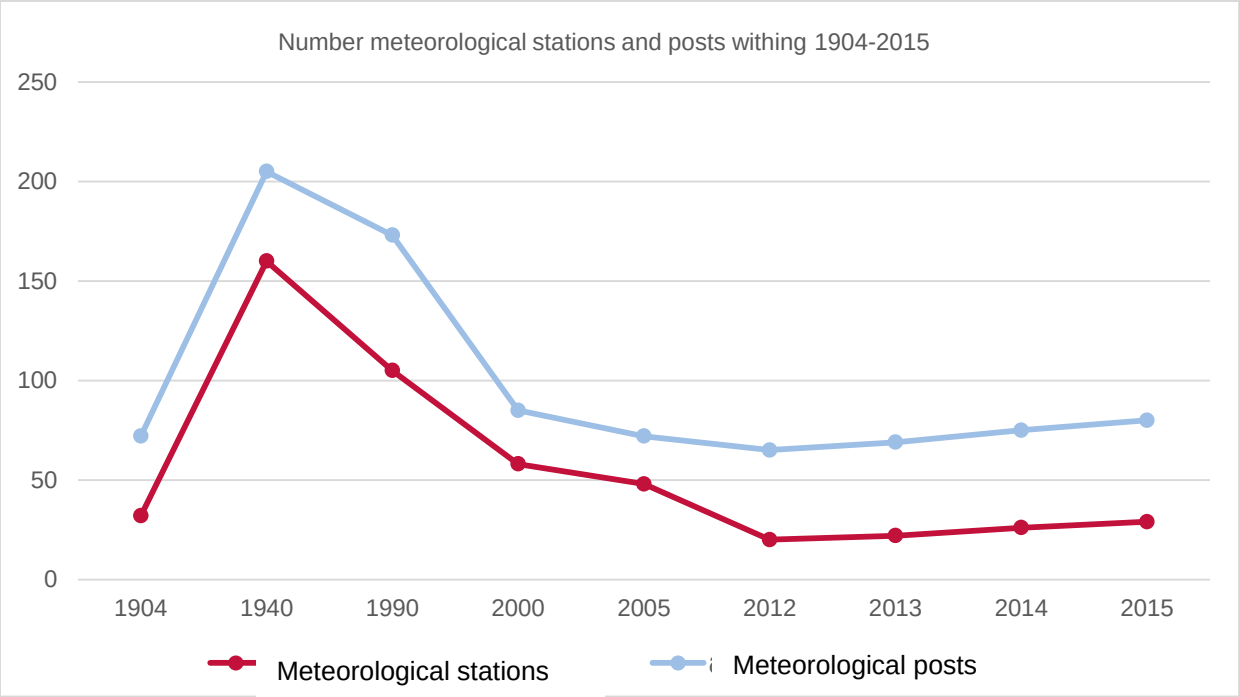
With such diverse circumstances and the permit system for water abstraction, streamflow measurements are fundamental to proper allocation of the water between the users, development of WAP and issuing permits.

3. HYDRO-METEOROLOGICAL MONITORING IN GEORGIA

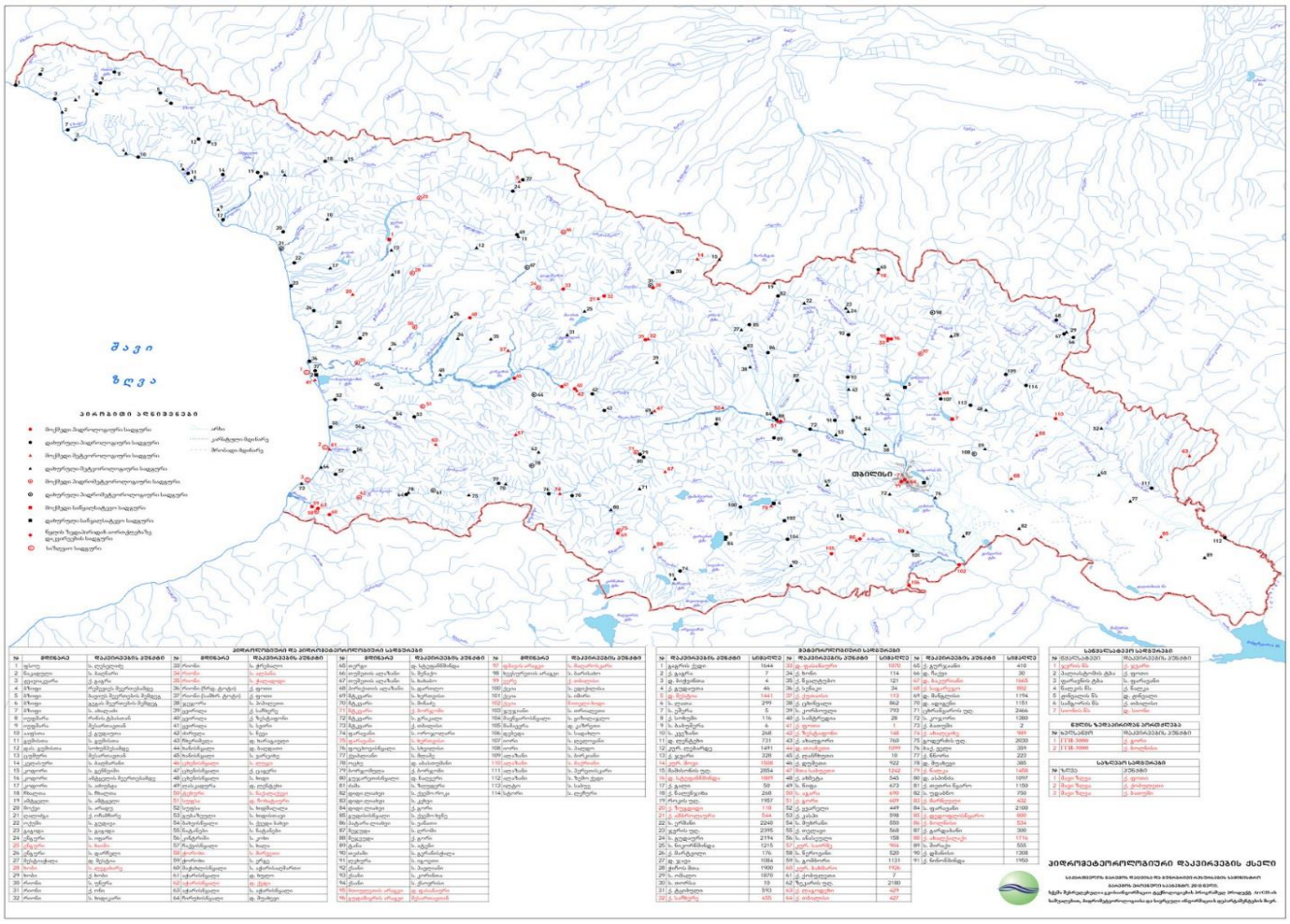
The hydro-meteorological service of Georgia counts more than 160 years of its existence. During this time, its legal status has changed many times. Currently, the service is a part of the NEA under MENRP

According to NEA, in Georgia in 1940, there were 160 meteorological stations. The downward trend started in the 1950s (145). By 1990, there were 105 meteorological stations operating in Georgia, and in subsequent years their number is characterized with a significant downward trend. Since 2012, the number of meteorological stations slightly increased (from 20 to 29). As for the meteorological checkpoints, most of them were in place in 1960 (100), in later years, their number has decreased (in 1970 - 78, 2005 - 24). Since 2010, the number of meteorological checkpoints slightly increased and by 2015 it reached 51 (sees Figure 1 and Map 1).

Figure 1: Number of hydro-meteorological stations and posts 1904-2015



Map 1: Hydro-meteorological monitoring network



Georgia is involved in the meteorological data exchange world system independently. WMO is provided with information from different countries once per 3 hours in a 24 hour regime, including from 14 meteorological stations of Georgia. At present, there are 17 hydrological and hydro-meteorological stations in Georgia, 26 meteorological stations and only two locations where water evaporation from surface observation takes place.

4. FINDINGS

At eight rivers of the Aragvi River Basin and 2 reservoirs, there are three active and 14 closed hydrological checkpoints. In addition, at two rivers (Narekvavi, Tezami), there is reconnaissance material.

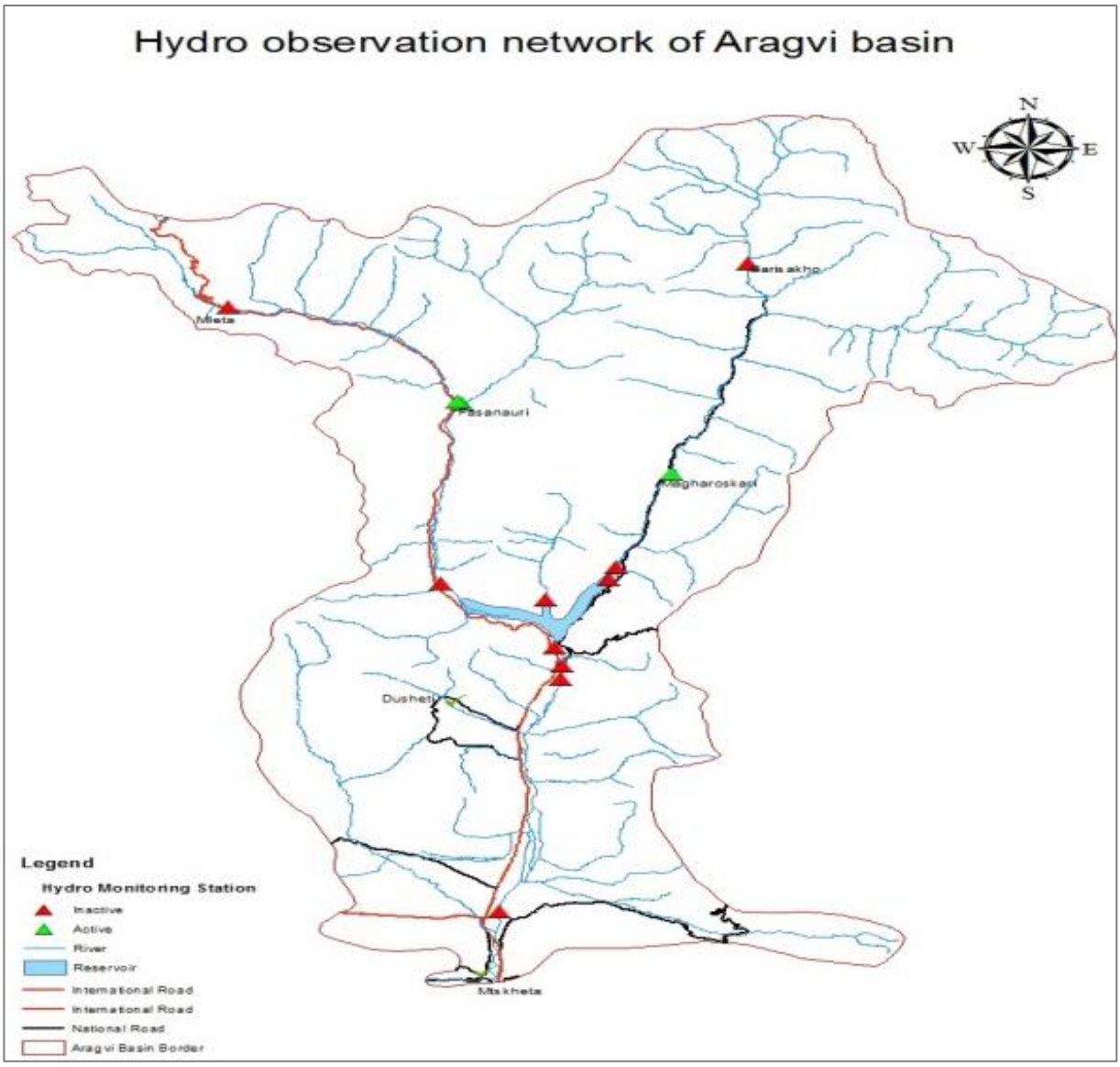
Table 1: The river Aragvi water level and discharge monitoring stations (the underlined text in the table reflects active stations).

River	Observation point	Water level and water discharge observation point	nQ
Aragvi	V. Tsikhisdziri	1973-80	8
Aragvi	B. Zhinvali	1914, 15, 28-34, 36-70	35
Aragvi	Zhinvalhesi	1985, 89-91	4
Aragvi	V. Chinti	1976-86, 87, 90, 91	14
Aragvi	V. Natakhtari	1931-33, 35-38	4
Mtiuleti's Aragvi	V. Mleta	1935, 37, 38, 42, 44-93	54
Mtiuleti's Aragvi	**B. Pasanauri**	**1937-2011**	**75**
Khidiskhevi	V. Tskere	1958-86	28
Gudamakari's Aragvi	**At confluence**	**1939-2011**	**73**
Arkala	V. Tandilaantkari	1948-53	6
Arkala	V. Zotikiantkari (before flooding)	1972-78	7
Khorkhula	V. Lausha	1972-78	7
Pshavi's Aragvi	**V. Magharoskari**	**1958-2011**	**53**
Pshavi's Aragvi	V. Tvalivi	1972-77	6
Pshavi's Aragvi	At confluence	1977-80	4
Khevsureti's Aragvi	V. Barisakho	1935-37	3

At present, the Aragvi River Basin hydrological and water quality monitoring is not sufficient. Currently, there are only three active hydrological stations (See map 2) in the boundaries of Aragvi River Basin:

- On Tetri Aragvi in Pasanauri;
- On Shavi Aragvi at confluence;
- On Pshavi's Aragvi in Magharoskari.

Map 2: River Aragvi hydrological observation network on Map 2.



Stream gauging involves obtaining a continuous record of stage (water level), making periodic discharge measurements, establishing and maintaining a relation between the stage and discharge, and applying the stage-discharge relation to the stage record to obtain a continuous record of discharge.

The stage is measured twice a day and the river runoff is calculated according to the Q-H curve. Q-H curve is updated twice a month, as a result of the relevant hydrometric measurement.

The streamflow formed on the upper section (catchment area upstream the Jinvali Dam) can be determined by the measuring discharge of the Jinvali Dam. Jinvali Dam has a capability to store approximately 1/3 of Aragvi

runoff, the water level measurement for the purposes of determination the water availability downstream the dam required.

The remaining catchment area of 1600 km^2 together with the discharge of Jinvali HPP form the streamflow downstream the Jinvali Dam. The streamflow formed downstream the dam can't be neglected in the process of streamflow determination at the outlet of the river basin. Respectively, the measurement of the streamflow at the outlet of the river basin is required as well.

5. RECOMMENDATIONS

1. The first priority is to gauge the water level in the reservoir, main streamflow downstream the Jinvali Dam and outlet of the river basin (See APPENDIX A);
2. With the agreement of the NEA and donor organizations, in accordance with launched projects, expand and replicate the technical and software programs in the river Aragvi basin;
3. It's necessary to arrange the ground water monitoring system.

APPENDIX A:

Justification for gauging station site specific location to provide data for the water allocation of the Aragvi River Basin

One of the first steps in developing a stream-gauging station is the selection of the general location of a site which, in our case, is the outlet of the river basin and the discharge of the Jinvali Dam.

Step One - Specific Site Location for Gauging Station

The process for streamflow gauging site selection continued with the specific site selection which, at the preliminary stage, should comprise reasonableness and possibility to use the location of non-active gauging stations. For justification of both old locations and searching for a new location, the process of selection referring to the criteria[3], clearly prescribed in WMO Manual on Stream Gauging:

a) The general course of the stream is straight for about 10 times the stream width, upstream and downstream from the gauge site if the control is a river reach (channel control). If the control is a section control, the downstream conditions must be such that the control is not drowned. The water entering a section control should have low velocity (see (f) below);

b) The total flow is confined to one channel at all stages and no flow bypasses the site as subsurface flow;

c) The stream-bed is not subject to scour and fill and is relatively free of aquatic vegetation;

d) Banks are permanent, high enough to contain floods, and are free of brush;

e) Unchanging natural controls are present in the form of a bedrock outcrop or other stable riffle for low flow and a channel constriction for high flow – or a waterfall or cascade that is unsubmerged at all stages. If a natural control is not available, then channel conditions should allow for the construction of an artificial control such as a weir or flume;

f) A pool is present upstream from the control at extremely low stages to ensure a recording of stage at extremely low flow, and to avoid high velocities at the stream ward end of stage recorder intakes, transducers, or manometer orifice during periods of high flow. The sensitivity of the control should be such that any significant change in discharge shall result in a measurable change in stage;

g) The gauge site is far enough upstream from the confluence with another stream or from tidal effect to avoid any variable influence the other stream or the tide may have on the stage at the gauge site;

h) A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gauge site. It is not necessary for low and high flows to be measured at the same stream cross-section;

i) The site is readily accessible for ease in installation and operation of the gauging station;

j) Within reach of a suitable telemetry system; good conditions for discharge measurements at all stages;

k) Instruments, shelter, and housing above all flood levels. Sensors with a range to measure floods and drought.

[3] World Meteorological Organization (WMO) – Manual on Stream Gauging Volume One Fieldwork

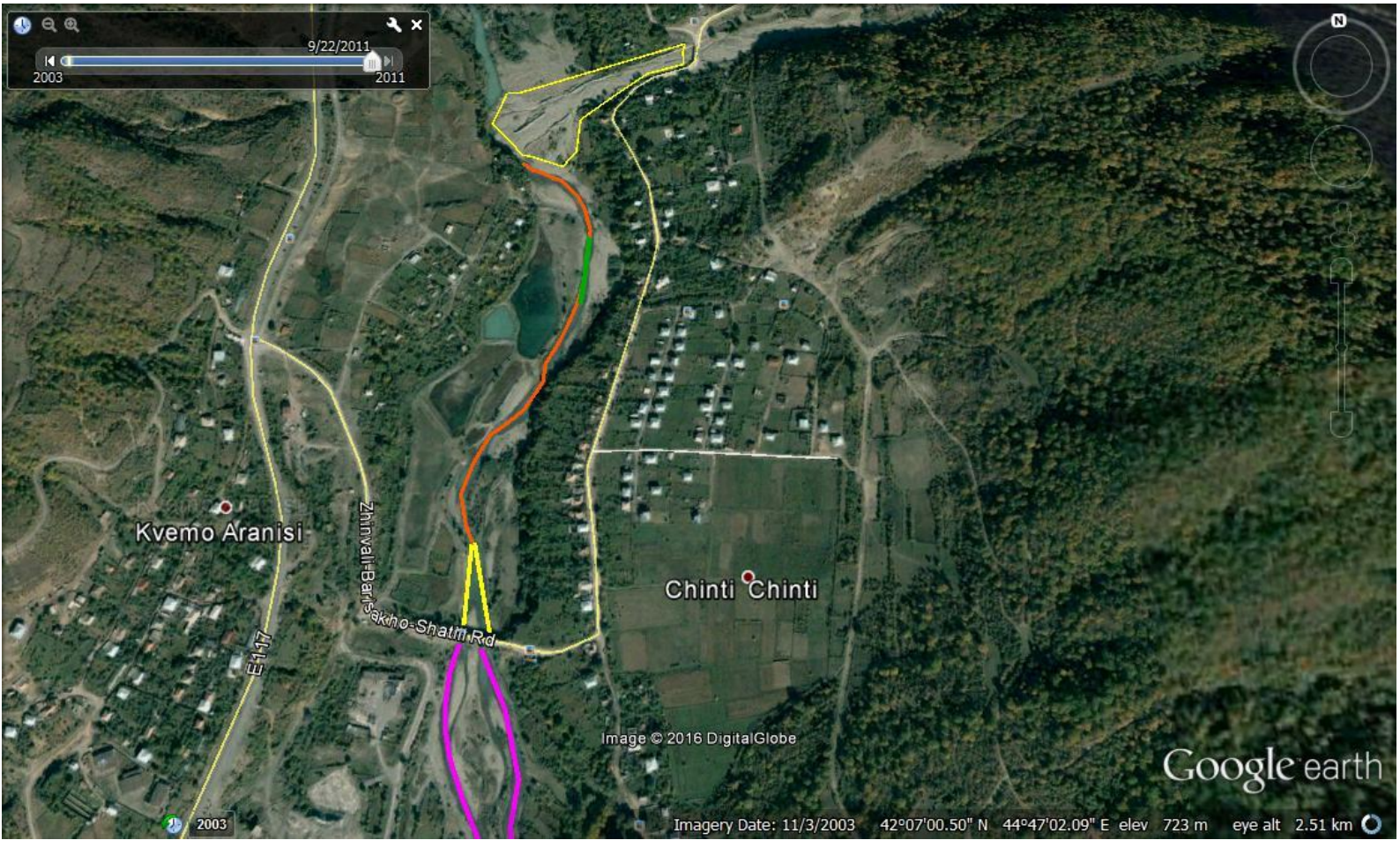
GAUGING STREAMFLOW – THE FORMER LOCATION

GAUGING ARAGVI STREAMFLOW NEAR THE VILLAGE CHINTI

Downstream the bridge to Chinti village, the total flow is not confined to one channel at all stages about 1 km thus it can't comply with criteria (b) from step one. The length of section before the confluence of tributary Saqanalis Khevi and Aragvi, upstream from the bridge is approximately 1 km. At this section the general course of the stream on one section with the length of 250 m can be found straight and stream confined to one channel. The said section seems affected by the sediment heavy load of Saqanalis Khevi small river at least during the rainy weather which will cause high uncertainties.

"Source of error i.e the uncertainties in velocity measurement by Acoustic Doppler Flow Measuring (ADFM) devices may be attributed to sediment transported in suspension, saltation or bedload (Wagner and Mueller, 2011). Doppler instruments require the presence of particles (or air bubbles) in the water column, but their optimal concentration is comparatively low and they must travel at the same velocity as the water. To date, the successful use of acoustics to measure flow velocity has been confined mostly to low to moderate ranges of suspended sediment concentration (SSC), i.e. less than a few grams per liter (Thorne and Hanes, 2002; Sontek Application Notes, 1997). Coarse particles transported near the channel bed can also affect seriously the ADFM response. These particles move slower than the water, which leads to an underestimation of the flow velocity (Nord et al., 2009; Blake and Packman in McIntyre and Marshall, 2010). To date, manufacturers have not provided any clear guidance and recommendations about the use of ADFM in situations where transported sediment is likely to affect instrument performance and scientific references to the problem are scarce."[4]

With the consideration of abovementioned together with the sediment trap efficiency of the Jinvali Reservior, which should ensure the lower load of sediments comparative the above discussed section, it is obvious that the site location closer to the dam has advantages comparative to the site discussed above. Moreover, the discussed sediment load issue which may lead to improper measurement and do not comply with criteria (c) from step one because the heavy load of sediments might be in occurrence.



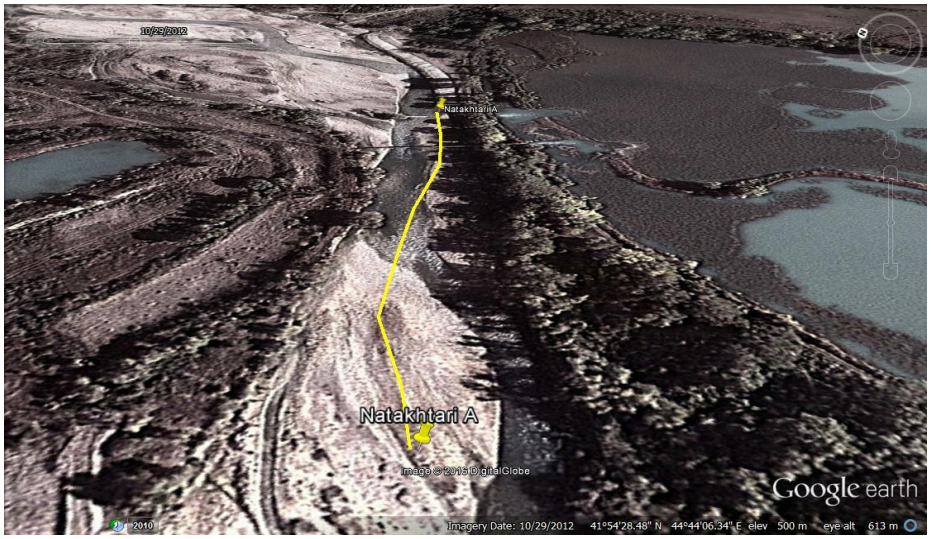
GAUGING STREAMFLOW NEAR VILLAGE NATAKHTARI - FORMER LOCATION

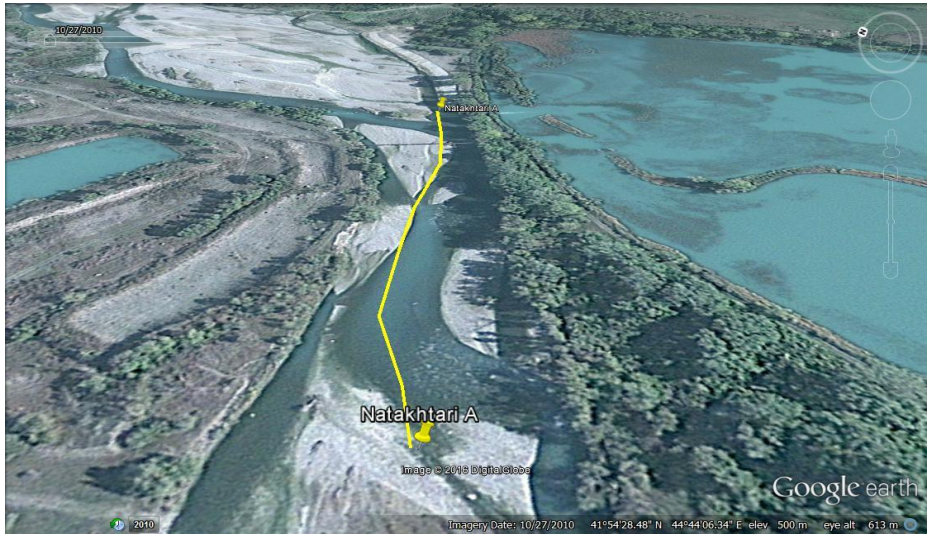
Downstream the confluence of the Tezami and Aragvi rivers, the total flow is not confined to one channel at all stages about 6.2 km thus the site specific location can't be discussed because it do not comply criteria (b) from step one.

However, the location Natakhtari, identified according the criteria (a) from step one and justified its compliance to other criteria. The changes of morphological elements such as river depth and width variation, changes of structure and substrate of the river bed which are evident from the Google Earth photos taken at different time, seems inherent. Respectively, the below provided site location can't comply with the criteria (b), (c), (d), (e).

Natakhtari A

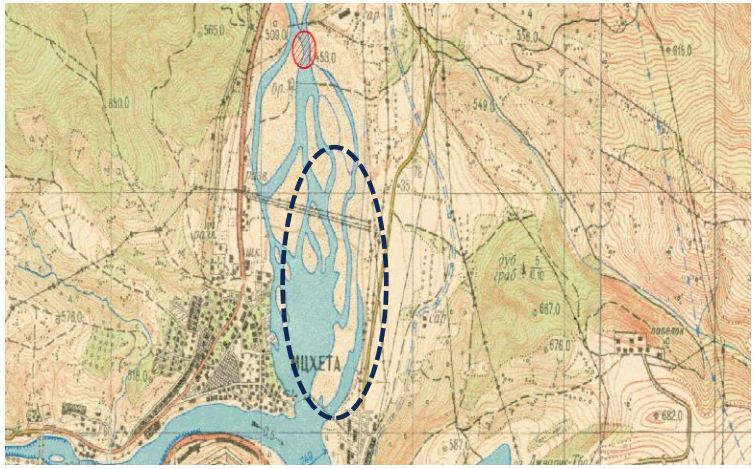
From the pictures taken at a different time it's obvious that the stream main flow time after time is changing direction or is not confined in one channel which is not appropriate for the gauging of the streamflow.

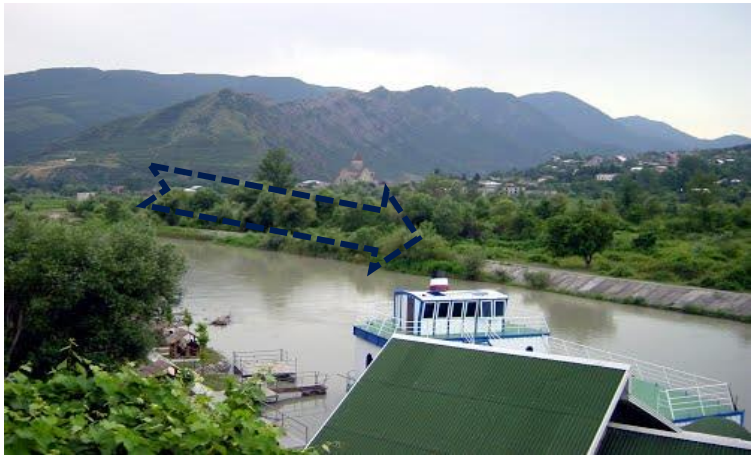




GAUGING ARAGVI STREAMFLOW AT THE OUTLET OF THE BASIN

The below discussed site near the confluence of Aragvi and Mtkvari rivers has characteristics to put runoff in artificial channel and has capability to comply all the criteria listed in step one. As it showed on the Soviet Military Map (scale 1:50000), the provided below section of the river wasn't confined in one channel causing the flooding of the nearby territories. Later, after the bank's artificial reinforcement, the main streamflow near the confluence of the Aragvi and Mtkvari has been confined in one channel at all stages until the confluence.





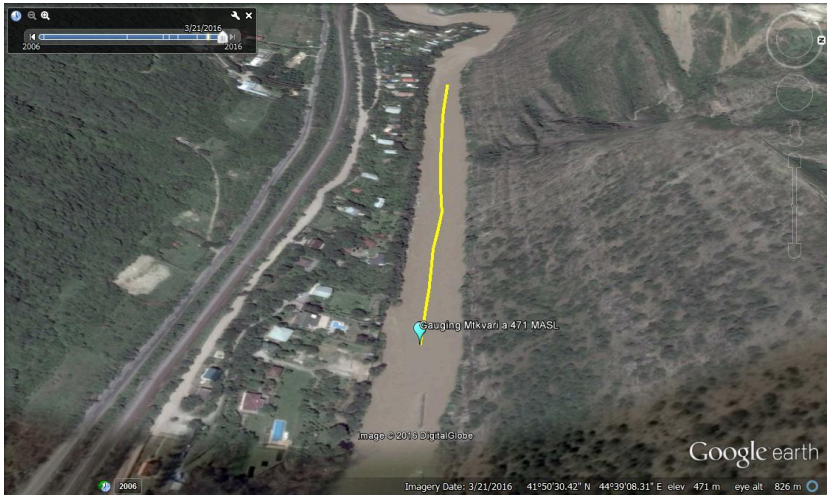
But the above sites seem unable to comply with the criteria (g) because the proposed site is not far enough upstream from the confluence of the Aragvi and Mtkvari rivers to avoid the impact of water level fluctuation caused by the Zaghesi HPP dam located right after the confluence downstream Mtkvari. The same levels above the sea level were fixed at the dam and at the outlet of the basin proposed for the gauging site location. Respectively, it seems that gauging the streamflow at the outlet of the basin might face difficulties and not comply criteria mentioned in step one and other alternative should be discussed.

POSSIBLE SOLUTION FOR THE MEASURING ARAGVI RIVER RUNOFF AT THE OUTLET OF THE BASIN

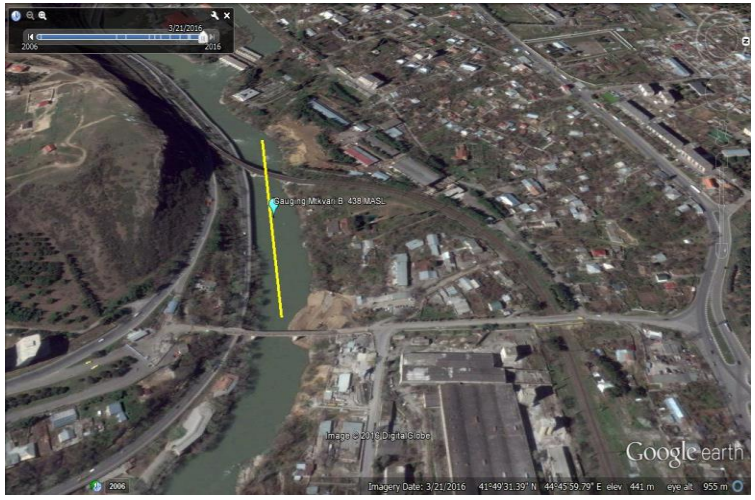
The Aragvi River Basin can be segregated into two sections, the runoff formed on a upper section which is represented by the catchment area upstream the Jinvali Dam and it can be determined by the measuring discharge of the Jinvali Dam downstream, whilst the measuring the runoff formed on the downstream the Jinvali Dam or the runoff at the outlet of the river might be difficult because of the circumstances described in above paragraphs.

Respectively, considering all the above mentioned, gauging the runoff of Mtkvari downstream the Zahesi HPP between the Zahesi district Railway Bridge and transportation bridge together with the gauging the Mtkvari runoff at the Dzegvi village in combination with the measuring runoff right after the Jinvali Dam and water Level in Reservoir will enable the calculation of Aragvi River runoff at the outlet of the river basin. The said sites located at River Mtkvari have the capability to comply with most of the criteria prescribed in step one.

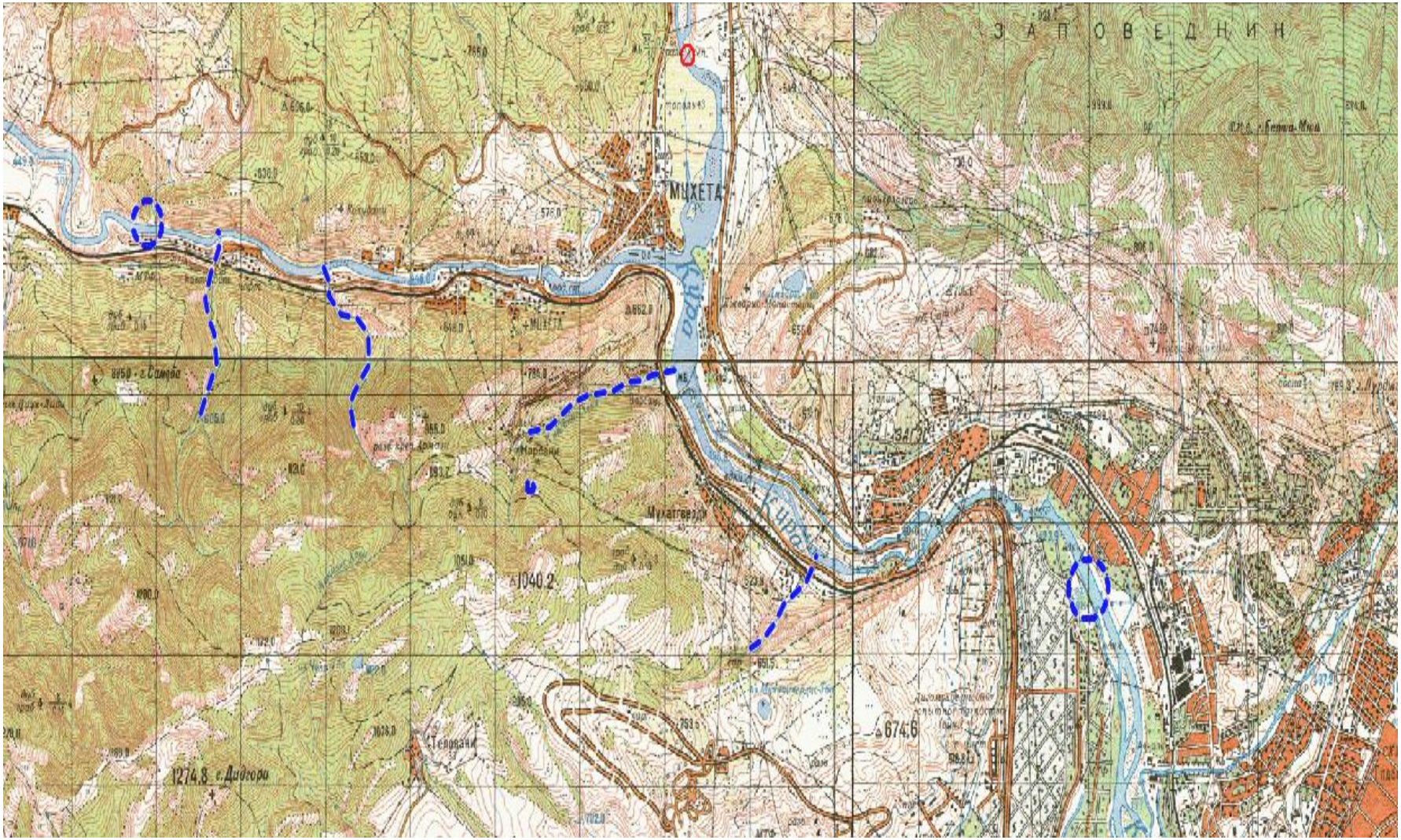
MMeasuring Streamflow near village Dzegvi downstream the railway bridge. Latitude 41°54'27.69"N - Longitude 44°44'2.46"E

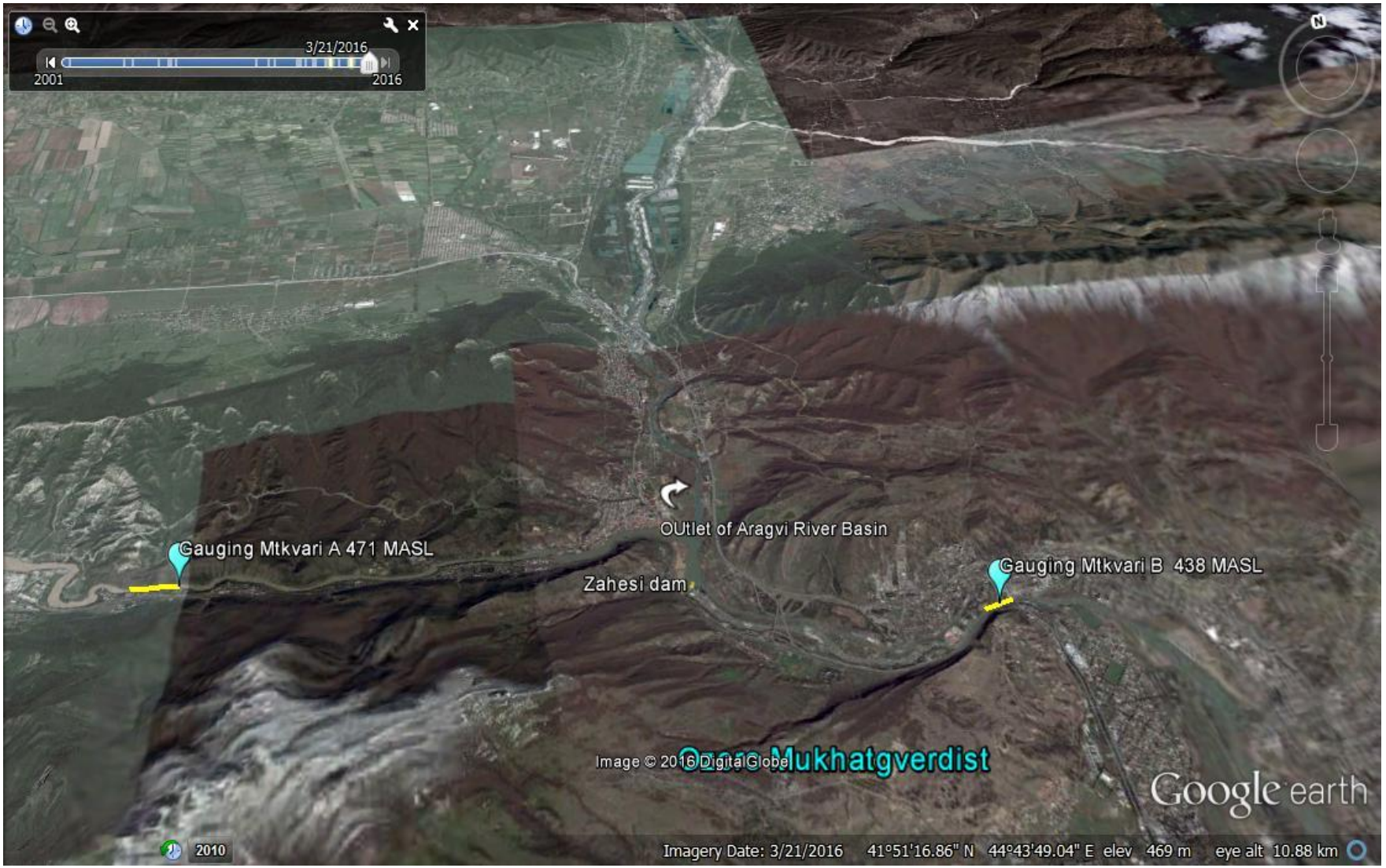


B Measuring Mtkvari streamflow near the Zaghesi bridge. Latitude 41°54'27.69"N - Longitude 44°44'2.46"E



The length of the section of Mtkvari River between the two proposed for gauging streamflow sites is approximately 10 km. However, Mtkvari has very small tributaries and springs falling under this section. Respectively, measuring the streamflow at said two points and calculating the difference will provide the firm basis for the calculation of streamflow at the outlet of the river basin




3/21/2016
2001
2016
OUtlet of Aragvi River Basin
Gauging Mtkvari A 471 MASL
Zahesi dam
Gauging Mtkvari B 438 MASL
Image © 2016 DigitalGlobe
Google earth
2010
Imagery Date: 3/21/2016 41°51'16.86" N 44°43'49.04" E elev 469 m eye alt 10.88 km

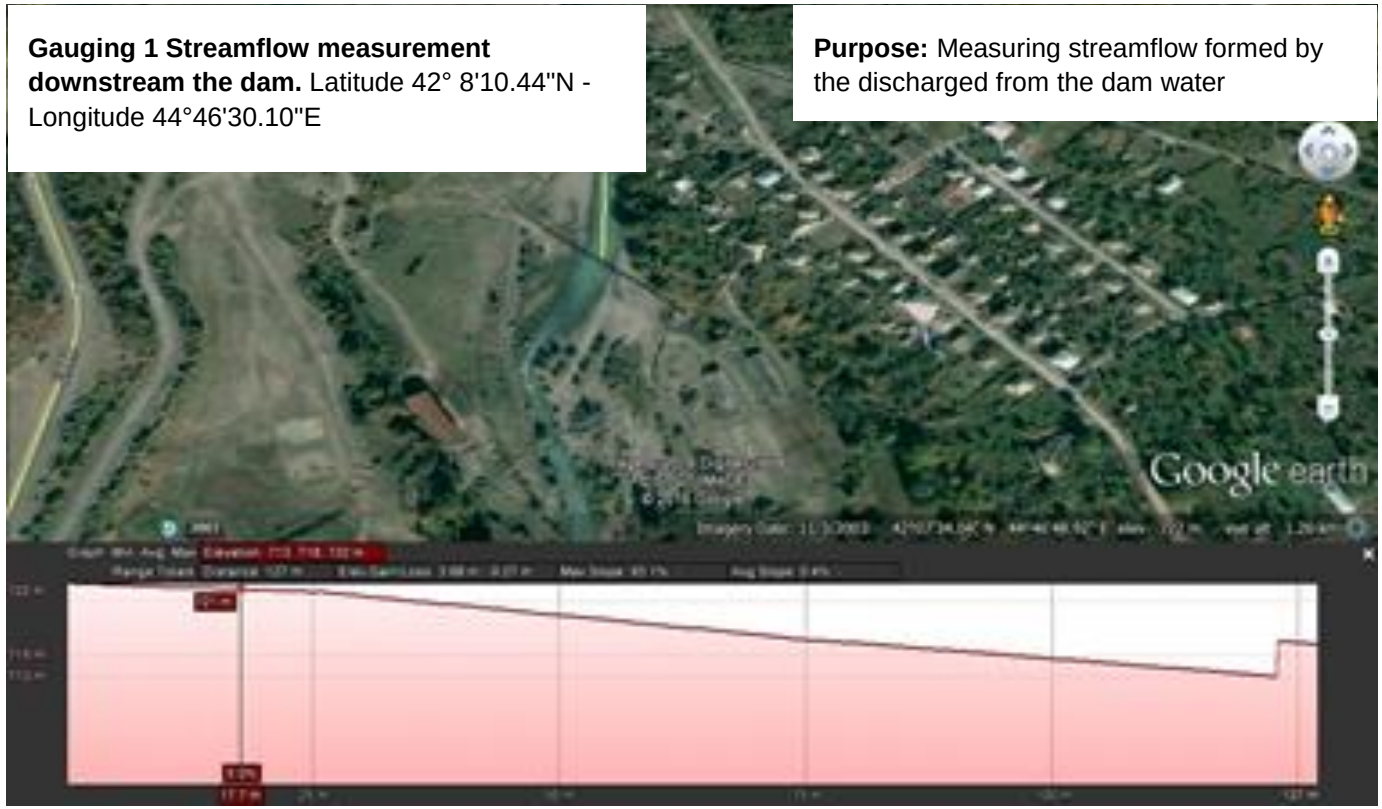
MEASURING DAM DISCHARGE AND WATER LEVEL IN RESERVOIR

The below provided site specific locations Gauging 1 and Gauging 2 proposed for the measuring the stage right after the tailrace of the Jinvaly HPP and parameter called the water level in reservoir and the respectively. Water level in reservoir will provide real time information on water stored in reservoir i.e. amount of water available to be released for environment, irrigation, industrial and energy production purposes, whilst measuring the stage right after the Jinvali HPP tailrace will provide the real time information on flood events and water available for downstream the Jinvali dam located water users and environment.

With the assumption of compliance to the criteria for site selection (b) and (C) which need field inspection, on the basis of google map visual inspection and data that can be obtained from said application, the provided below site location for the measuring the dam discharge seems to have a capability to comply with all the criteria's mentioned in "Step One".

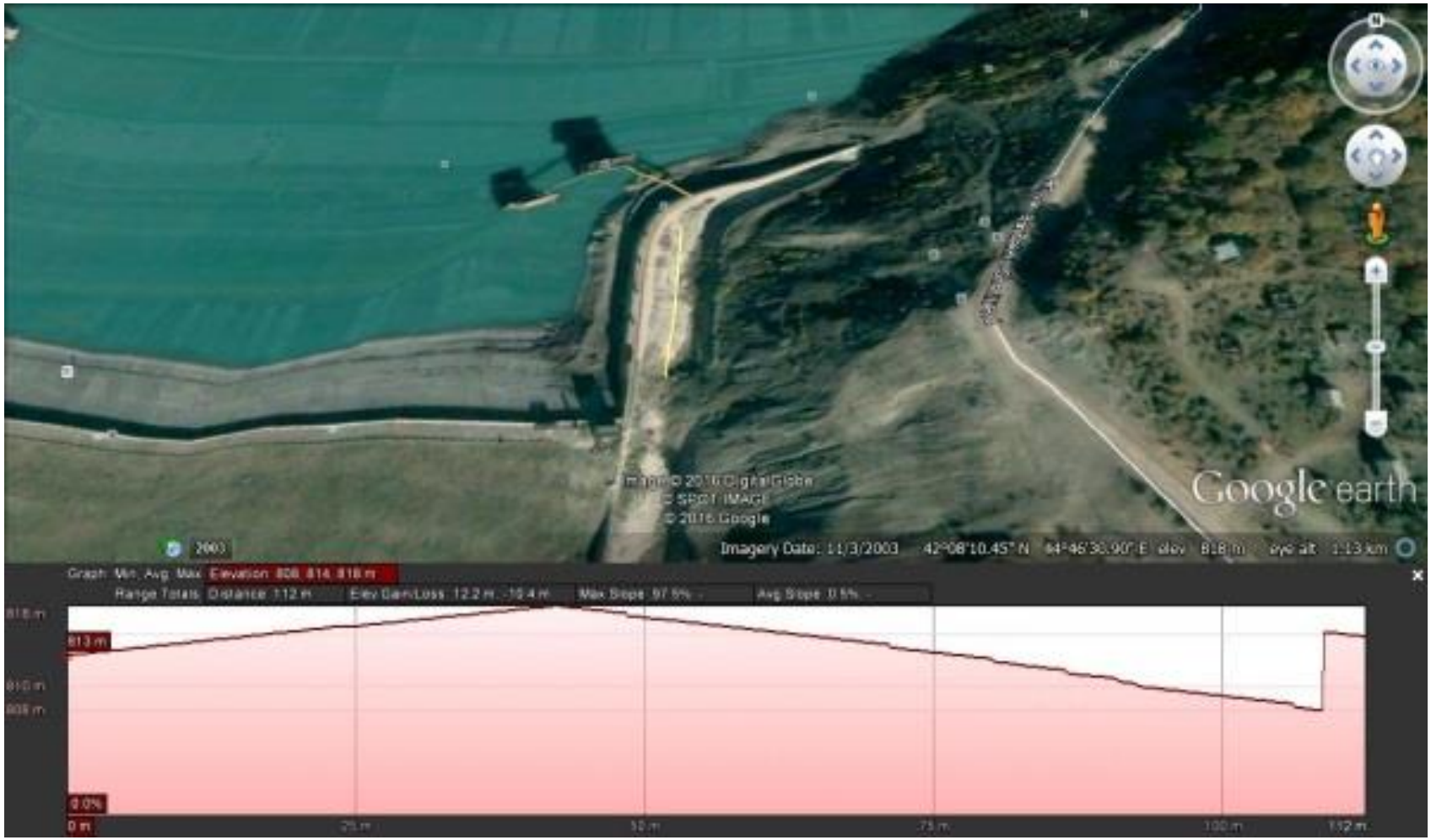
Gauging 1 Streamflow measurement downstream the dam. Latitude 42° 8'10.44"N - Longitude 44°46'30.10"E

Purpose: Measuring streamflow formed by the discharged from the dam water

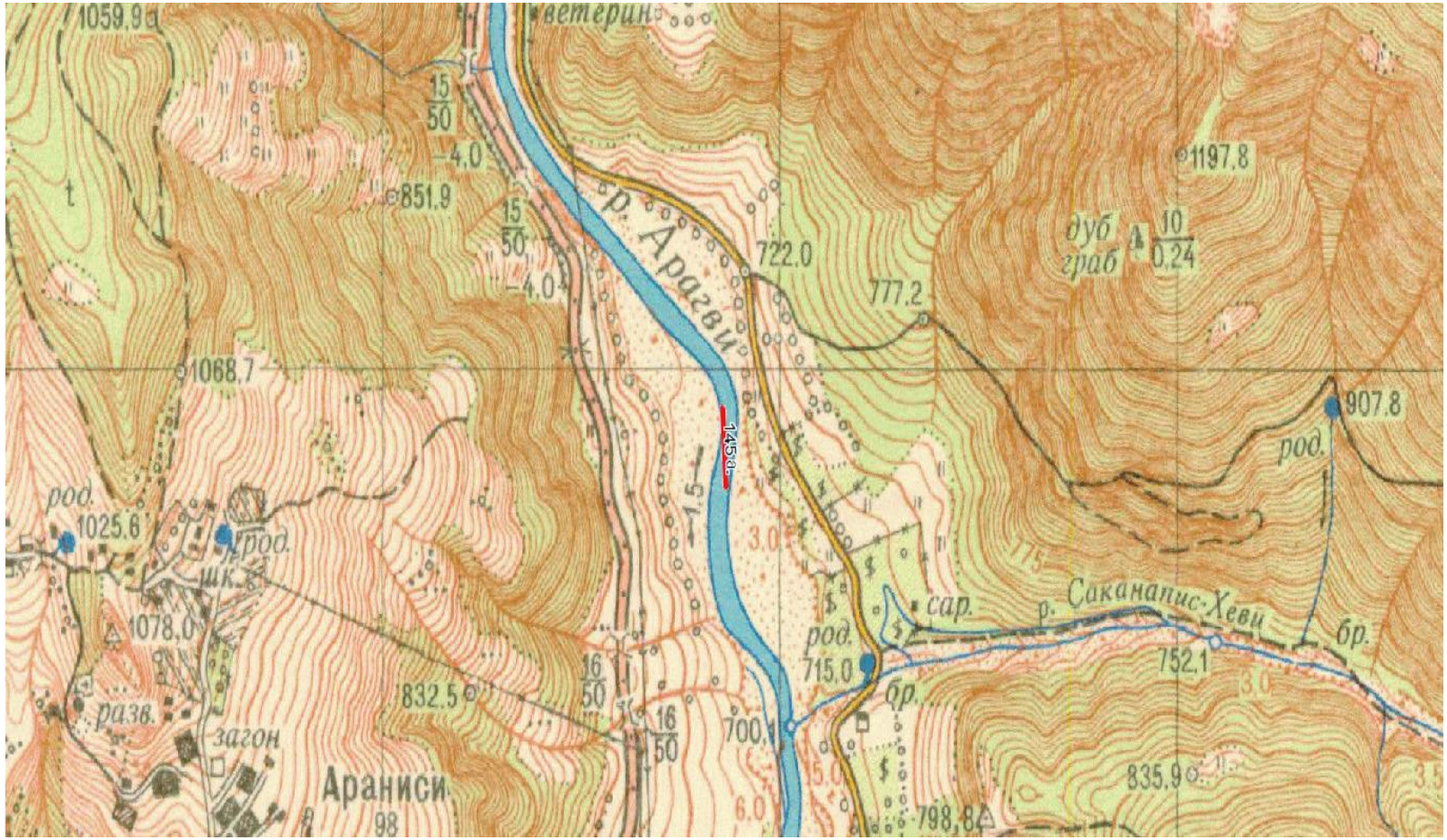


Gauging 2 water level in the dam. Latitude 42° 7'34.73"N - Longitude 44°46'46.13"E

Purpose: Measuring water level in reservoir for the computation of water available for release



For the gauging 1 site specific location following the isotype lines on the Soviet military map below banks seem permanent and free of brushes and trees. Banks also seem permanent and high enough to contain floods.



ACTIVITIES REQUIRED FOR COMPLETING THE SELECTION OF SITES FOR GAUGING THE ARAGVI STREAMFLOW

A continuous record of stage[5] is obtained by installing instruments that measure and record the water surface elevation in the stream. Respectively, during the selection of the site locations, most modern gauges were considered with ultrasonic and radar sensors which can be easily mounted on bridges, superstructures of channels or the ceilings of closed channels, have low weight and requires non-intensive power supply using solar panels and batteries. The type of gauges recently used and those that use ultrasonic and radar sensor because this kind of sensors can be easily mounted on bridges, superstructures of channels or the ceilings of closed channels, have low weight and requires characterization by non-intensive power consumption which can be ensured with solar panels and batteries. Also, it cannot be harmed by sediments and floating waste, requires very low maintenance and has an increased reliability, especially in flood water situations.

As most of the devices in the world, mentioned kind of devices together with its advantages also has the requirements on special conditions for the installation and the proper functioning. The main criteria for measurement sites are the properties of the riverbed, the water surface and the flow conditions[6].

- The riverbed must not change to ensure a consistent measurement. The water surface must not be flat. Wavelets should be visible. Stones, maelstroms or standing waves should not occur within the measuring area.
- In general the velocity distribution at the measurement site must not be changed by time variable influences like fluctuating inflows and regulated weirs
- In the viewing range of the radar sensor no stationary waves may occur as they may influence the velocity and water level measurement strongly. Stationary waves are caused by pillars of bridges, sharp edges in the bed or big stones and their appearance is moreover depending on the water level
- The cross section in the range of the complete measurement has to be consistent. Changes are for example caused by widenings or narrowing's of the river bed
- The cross section of the river must not change as this causes the need of a new site calibration
- The radar sensor can be mounted in a range from 0.5 to15 m above the water surface or river bed.

For the final approval of the site specific location the selection process requires to be supplemented by the:

- Instrumental topographical survey;
- A survey of the bottom of the river and banks soil, and description of physical and mechanical properties;
- Determination of the flow direction and velocity;
- Detailed survey of the site carried out after its selection and approval; and
- NEA Department of Hydrometeorology -They should provide approval and comprehensive material for the subsequent selection of the type of Gauging Station, design and construction of buildings or station and/or reshaping the stream channel to make it close to the ideal shape required for the measurements.

[5] Water level in a stream is its stage. Streamflow is how much water, how fast and how high Water pressure shows stage height (http://www.ecy.wa.gov/programs/eap/flow/methods.html)

[6] Product Leaflet Non-Contact Discharge Radar for measuring the river flow. (http://www.sommer.at/en/products/water/rq-30-rq-30a)

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