Dariali Energy

Dariali Hydropower Project

Advice on Aquatic Biodiversity Conservation

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Executive Summary

Dariali Energy (DE) JSV is developing the Dariali Hydroelectric Power Plant (HPP) Project in the Kazbegi Municipality District of central Georgia. The plant will comprise a run-of-river, 108MW-capacity hydropower facility with associated substation and electricity transmission infrastructure. A spillway dam will impound a section of the Tergi River and an intake structure will divert the water into a settlement basin and headrace tunnel towards the powerhouse. From the powerhouse the tailrace tunnel will take the water to the location where it will re-join the Tergi River channel. This 'diversion section', from the headrace dam to the tailrace tunnel outlet, will bypass approximately 5km of the Tergi River.

DE has commissioned ARUP to review the appropriateness of the proposed minimum environmental flow required to support the aquatic ecosystem between the headrace and tail race and sustain populations of the native fish *Salmo trutta fario*. In the project area, the presence of *Salmo trutta fario* was confirmed by the baseline studies only in the tributaries of Tergi river upstream from the proposed Dariali HPP project.

Currently the scheme makes an allowance of 10% of the estimated average annual flow (as is standard practice in Georgia) at the intake, based on gauged records observed at a nearby gauging station from 1928 to 1940 and from 1953 to 1990. This equates to a flow of 2.54 m^3/s.

The United Kingdom Technical Advisory Group (UKTAG) has produced best practice guidance on deriving environmental flow requirements. The approach uses the 'building blocks' methodology assumes that the natural flow regime will provide the best possible conditions for ecosystem functioning, and identifies key flows (building blocks) required to continue supporting that functioning. The table below identifies the building block flows likely to be of relevance to *Salmo trutta fario* and the issues that the HPP proposals raise.

'Building block' flow required to…	**Issues**
Support spring migrations (April –June) into and within the system.	The onset of migration is affected by a number of factors , but increased temperature and river flow are of primary importance. Following implementation of the scheme flows will still increase rapidly in the Spring. A portion of the initial increase will be abstracted and the peak flows downstream will also be reduced. This impact will be further assessed through monitoring. (assuming such migrations happen periodically, and not in a phased manner in response to food availability and other system conditions).
Support autumn migration and spawning.	Flows will be unaffected in any spawning areas upstream of the proposed dam. In the reach downstream of the dam, the flows will be lower during the autumn months. Flows need to be sufficient to support this autumn migration and the adequacy of the proposed environmental flow should be assessed through monitoring. (assuming such migrations happen periodically, and not in a phased manner in response to food availability and other system conditions).
Sustain populations of benthic fauna and flora at the base of the ecosystem.	The proposed flow reductions resulting from the abstraction will reduce the extent of available aquatic habitats, particularly in braided reaches, between the dam and the tailrace. It is thought unlikely that fish use these areas as spawning grounds nor that fish feed in, or migrate through, these reaches during the winter months. However, this will be confirmed through monitoring and adjustment of mitigation measures where necessary.
Refresh channel habitats and disperse biota and supraficial debris.	The proposals will have little impact on the periodic flood flows responsible for these processes.

The environmental flow of 2.54 m^3/s is likely to be sufficient to allow fish to travel up the proposed fish pass, provided it is designed in accordance with best practice. This figure is also consistent with the environmental flow that would be legally required for the same river in other countries, including EU countries with alpine river basins. This environmental flow value is therefore considered as a reasonable initial value to develop the Project until the further site specific data is available.

There is currently insufficient scientific information available on the river ecology and particularly on the specific environmental flow requirements of *Salmo trutta fario*. In addition, the Tergi river environment is changing under the influence of two recent run-of-river hydropower schemes immediately downstream from the proposed Dariali HPP: Larsi HPP, Georgia, under completion and Ezminskaia HPP Russia (completed). It has therefore been decided to adopt the precautionary approach through a monitoring driven adaptive management plan. Adaptive management will allow, for example, temporary adjustments in the environmental flow to support seasonal migrations around April and October, if such migrations were confirmed by the fish monitoring program. It is therefore recommended that:

- A monitoring programme is developed to confirm that the proposed minimum environmental flow is sufficient to support the above requirements;
- The design be reviewed to ensure that the sluice directly adjacent to the fish pass can, if necessary, be adjusted to pass forward environmental flows in the river in a manner that ensures fish are attracted to the fish pass;
- Geomorphological monitoring (focused on immediate channel continuity, fine sediment flushes, geomorphological response to the altered regime and extent of freezing) is undertaken to inform adaptive management and ecological monitoring;
- At least one season of monitoring occurs prior to the scheme being commissioned and continues for at least three years after commissioning (this could be associated with PhD research);
- A management regime is established based on operational experience that takes the results of the monitoring directly into account;
- The above is used to inform a public engagement, education and awareness-raising strategy.

1 Introduction

Dariali Energy (DE) JSV is developing the Dariali Hydroelectric Power Plant (HPP) Project in the Kazbegi Municipality District of central Georgia. The plant will comprise a run-of-river, 108MW-capacity hydropower facility with associated substation and electricity transmission infrastructure. A spillway dam will impound a section of the Tergi River and an intake structure will divert the water into a settlement basin and headrace tunnel towards the powerhouse. From the powerhouse the tailrace tunnel will take the water to the location where it will re-join the Tergi River channel. This ‘diversion section’, from the headworks to the tailrace tunnel outlet, will bypass approximately 5km of the Tergi River.

Ove Arup & Partners International Limited (Arup) has been commissioned by DE on 3 December 2013 to provide advice on the implications of the Power Plant for aquatic habitat biodiversity on the Tergi River. This work has been completed in consultation with European Bank for Reconstruction and Development (EBRD) which is currently considering entering into a financing agreement with DE to enable the proposed scheme.

The report has been prepared solely for the benefit of DE and EBRD in connection with this development. It shall not be relied upon or transferred to any other party without the prior written authorisation of Arup. The report does not address any other potential environmental impacts that may result from the development, other than those related to environmental flows, geomorphology and aquatic ecology (predominantly fish populations).

Arup does not accept any liability for the accuracy or otherwise of any information derived from secondary sources, however, endeavours have been made to verify the suitability and appropriateness of information obtained in this way.

2 Scope

The original scope outlined in the Terms of Reference[i] was as follows:

- Project inception meeting/conference call with the Lenders and the Borrower to agree the final Terms of Reference and required deliverables.
- Desk based study of existing information, issue request for further information where it is available.
- Meet the Borrower, the Borrowers consultant team and the Lenders to discuss the proposed approach and outline of the works required.
- Visit the Project location with the Borrower and the Lender's representatives to observe conditions in the River Tergi including the river morphology, flow characteristics, construction activities and project design.
- Provide an expert view on the proposed Project and its likely impact on river characteristics including calculation of acceptable environmental flow limits on the basis of known or potential river biodiversity and conservation status.
- Provide a well-argued and readily implementable list of recommended actions and adaptive mitigation measures, including engineering design solutions and operational controls, if necessary, to further monitor and minimise the impacts of the proposed Project on the hydro ecology including fish populations.

Following an inception meeting, the site visit was undertaken by Dr David Hetherington on 11th and 12th December 2013. A desk top review of relevant information was carried-out concurrently by UK-based staff. Following discussions with EBRD, the content and requirements for Arup's report were agreed as follows:

- Critically review the existing information as provided by DE and EBRD;
- Report the findings of the site visit;
- Identify and comment on the relevant legislation, special conditions in Georgia and the operation and management of the HPP release regime in relation to EU standards;
- Provide context with regard to existing guidance and methodologies on the formulation of environmental flows;
- Recommend an ecologically-focused, suitable environmental flow for the impacted reach of the river based on current standards, geomorphological evidence and a high-level hydraulic analysis;

2.1 Context

The European Bank for Reconstruction and Development (EBRD) is acting as lender to DE (the borrower) in relation to the development of the Dariali Hydropower (HPP) scheme. A number of relevant studies have been undertaken related to scheme feasibility and environmental and social impacts (see section 2.2 for a list of these studies).

The EBRD has raised concerns about the potential environmental impact of the proposed Dariali HPP operation on the river regime. Specifically, questions have been raised regarding the appropriateness of the proposed minimum environmental flow between the headrace (HPP intake, where the river water is abstracted) and tail race (HPP outlet, where the water is returned to the river downstream). The environmental flow is a theoretical minimum flow required to support the aquatic ecosystem. Currently the scheme makes an allowance of 10% of the average annual flow.

The EBRD have asserted their commitments to environmental and social sustainability in their E&S Policies[12], stating that the projects they finance must be socially and environmentally sustainable. The EBRD is committed to promoting environmentally sound and sustainable development pursuant to its constituent treaty (the Agreement Establishing the EBRD) in the full range of its activities. The proposed Dariali Hydropower Project has been classified by EBRD as Category A. For Category A the borrower must conduct an assessment of social and environmental impacts and risks and propose mitigation and management measures to mitigate any negative impacts.

In the words of ERBD, "*A proposed Project is classified as Category A when it could result in potentially significant and diverse adverse future environmental and/or social impacts and issues which, at the time of categorisation, cannot readily be identified or assessed and which require a formalised and participatory assessment process carried out by independent third party specialists in accordance with the Performance Requirements*".

The EBRD's Environmental and Social Policy details 10 Performance Requirements (PRs), covering all aspects of Environmental and Social planning. The key PR relevant to this study is Performance Requirement 6 (PR6) - Conservation and Sustainable Management of Living Natural Resources. The objectives of PR6 are to:

- Protect and conserve biodiversity;
- Avoid, minimise and mitigate impacts on biodiversity and offset significant residual impacts, where appropriate, with the aim of achieving no net loss or a net gain of biodiversity;
- Promote the sustainable management and use of natural resources;
- Ensure that Indigenous Peoples and local communities participate appropriately in decision-making;

[1] IFC, 2012. International Finance Corporation's Policy on Environmental and Social Sustainability.
[2] ERBD, 2008. Environmental and Social Policy

- Provide for fair and equitable sharing of the benefits from project development and arising out of the utilisation of genetic resources;

- Strengthen companies' license to operate, reputation and competitive advantage through best practice management of biodiversity as a business risk and opportunity;

- Foster the development of pro-biodiversity business that offers alternative livelihoods in place of unsustainable exploitation of the natural environment;

2.2 Available information

The previous project specific studies used in this report include:

- Environmental and Social Impact Assessment Report; 2011; Stucky Caucasus / Gamma[3];
- Technical Due Diligence on Dariali HPP; 2013; Fichtner[4];
- Dariali Hydroelectric Project – Feasibility Study; 2011; Landsvirkjun Power / Verkís[5];
- Dariali Hydroelectric Project – Project Design Report; 2012; Landsvirkjun Power / Verkís[6];
- Brief Hydrological Description of Tributaries Existing on the Dariali HPP Diversion Section; 'Gamma' note as sent by Dariali Energy on 08/12/2013[7];
- Dariali HPP and Compensation Sites Comparative Analysis, Botanical Component; 2013; Institute of Botany, Ilia State University[8];
- Dariali HPP Project Area and Compensation Sites Comparative Analysis, Zoological Component; 2013; Institute of Botany, Ilia State University[9];

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[3] Environmental and Social Impact Assessment Report; 2011; Stucky Caucasus / Gamma
[4] Technical Due Diligence on Dariali HPP; 2013; Fichtner
[5] Dariali Hydroelectric Project – Feasibility Study; 2011; Landsvirkjun Power / Verkís
[6] Dariali Hydroelectric Project – Project Design Report; 2012; Landsvirkjun Power / Verkís
[7] Brief Hydrological Description of Tributaries Existing on the Dariali HPP Diversion Section; "Gamma" note as sent by Dariali Energy on 08/12/2013
[8] Dariali HPP and Compensation Sites Comparative Analysis, Botanical Component; 2013; Institute of Botany, Ilia State University
[9] Dariali HPP Project Area and Compensation Sites Comparative Analysis, Zoological Component; 2013; Institute of Botany, Ilia State University

2.3 International best practice guidance

The Report of World Commission on Dams[10] highlights the need to balance demand of water resources and social environmental concerns, sustaining river habitats and livelihoods. The report recommends that environmental flows should be tailor made for the specific setting of the scheme. A key guideline is that the project should be able to adapt to changing contexts, and use regular monitoring to inform adaptation to changing needs.

The International Hydropower Association (IHA) has produced a protocol[11] relevant to promote sustainable use of hydropower that can also be relevant for the scheme. The protocol can be used to assess the sustainability of a hydropower project that may be used together with monitoring. Among other topics, the protocol considers the issue of downstream flow regimes.

The United Kingdom Technical Advisory Group (UKTAG)[12] has produced best practice guidance regarding WFD requirements in impounded water bodies. The approach uses the building blocks methodology, which may be appropriate in order to assess how understanding of current conditions can be used to define environmental flow requirements for the Tergi River at the Dariali HPP location. The methodology is based in a natural flow paradigm that assumes that the natural flow regime will provide the best possible conditions for ecosystem functioning, and identifies key flows (building blocks) required to continue supporting that functioning. In addition, appropriate and measurable ecological indicators, adapting suitable survey methodologies to the local context must be used. The guidance recommends using a risk-based approach that identifies risk and flow needs for the chosen habitat or ecological element, and stresses the importance of using and adaptive management approach.

Similar guidance has been discussed by scientists and practitioners[13,14]. A common subject in all guidance is the stress in the importance of monitoring and adaptive management after recommendations have been made and schemes have been implemented, and the integration within schemes of tools that will permit making changes to operational conditions such as release of environmental flows.

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[10] World Commission on Dams, 2000. Dams and Development, a new framework for decision-making. The report of the World Commission on Dams.
[11] IHA, 2011. Guidelines of the International Hydropower Association- Sustainability Assessment Protocol.
[12] UKTAG, 2013. River Flow for Good Ecological Potential. Final Recommendations.
[13] Acreman, M, Aldrick, J., Binnie, C., Black, A, Cowx, I, Dawson, H, Dunbar, M., Extence, C., Hannaford, J., Harby, A., Holmes, N., Jarret, N., Old, G., Peirson, G. and Webb, J. 2009. Environmental flows from dams: the water framework directive. Engineering Sustainability, 000, p 1-10.
[14] Sniffer, 2012. Ecological indicators of the effects of abstraction and flow regulation; and optimisation of flow releases from water storage reservoirs.

2.4 European Legislation and Guidance

Concerns have been raised by the Minister of Environment and Natural Resources Protection regarding the scientific basis of calculation the proposed environmental flow[3]. This is also of concern to the lenders.

The Dariali HPP scheme has produced an Environmental and Social Impact Assessment (ESIA[3]), using the template guidance and requirements of the European Union (EA) Environmental Impact Assessment (EIA) Directive[15]. This was designed to ensure that the requirements of the lenders are addressed to ensure that the project will not harm people and the environment. Some of the concerns identified by the ESDD were addressed by the recommendations and monitoring and management strategy proposed by this EIA.

Section PR6 of the EBRD Environmental and Social policy refers to the conservation of biodiversity and sustainability management of living natural resources. The policy highlights the need to protect habitats and biodiversity in projects, and in particular aims to avoid, minimise and mitigate the impacts on biodiversity of financed projects, to offset residual impacts and to ensure that ecological integrity and functioning of the ecosystem is not compromised or the habitat is not deleted to the extent that it can no longer support viable populations of its native species.

The lenders' policies stress that it is crucial that all the necessary steps are taken to ensure that best scientific knowledge and practice is used to set the required environmental flows and appropriate monitoring and adaptive management tools are used to be able to deal with uncertainties and assumptions. In particular, it is proposed that projects must be designed in compliance with **regulatory requirements** and **good international practice**. EBRD also aims to promote **EU environmental standards** and requests that a precautionary approach be taken when assessing potential impacts of schemes, which is also advocated by EU regulations[16].

Together with the Habitats Directive[17], the key EU regulatory legislation relevant to aquatic biodiversity and river ecosystems is the Water Framework Directive (WFD)[18]. This requires that the ecological status of all water bodies be assessed by EU Member States. This information should be detailed in a River Basin Management Plan (RBMP) together with measures required to ensure that all water bodies achieve Good Ecological Status. All new (and current on-going) activities in the water environment need to be guided by the requirements of the WFD in member states, to ensure that they do not cause deterioration of the aquatic ecosystems, promote a sustainable use of water as a natural resource and conserve habitat and species that depend directly on water.

Georgia is not an EU Member State. River Tergi does not have a RBMP and existing ecological status has not been defined. Nevertheless, the guidelines and objectives of the WFD can still be used as the basis for assessing whether the scheme will cause deterioration of the ecological status of River Tergi.

[15] Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment (as amended). The current codified version is Directive 2011/92/EU
[16] EU, Article 191 of the Treaty on the Functioning of the European Union.
[17] Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.
[18] Directive 2000/60/EC of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

3 Scheme description

This section provides a summary of the various structures and their operation within the Dariali Hydro Power Project. The majority of the information was taken from Landsvirkjun Power & Verkis, Dariali Hydroelectric Project Project Design Report, (March 2012) offers a summary of the significant information associated with the proposed HPP, described in more detail below in **Table 1**.

Table 1 Significant information relating to the proposed Dariali HPP (as given in the March 2012 – Project Design Report by Landsvirkjun Power & Verkis)

Hydrological data	Mean river flow at intake	24.9 m^3/s
	Rated turbine discharge	33 m^3/s
	Sanitary flow	2.4 m^3/s
	Average discharge through station	22.4 m^3/s
	Intake dam design flood	515 m^3/s
	Maximum recorded flow	(1928) 481 m^3/s
Headworks	Spillway crest elevation	1729.3 m a.s.l.
	Highest flood water level (FWL)	1732.1 m a.s.l.
	Empty intake pond	1725 m a.s.l.
	Total volume of intake pond	7000 m^3
	Length of spillway dam	36 m
	Sand sluices. 2 pcs	6.0x6.0 m
	Spillway capacity at FWL	220 m^3/s
	Sand sluices capacity at FWL	280 m^3/s
	Trashracks. 3 pcs	4.0x2.2 m
	Intake gates. 3 pcs	4.0x2.2 m
Conduit- intake to sand basin	Length	326 m
	Type	Buried steel pipe. GRP-pipe or Concrete conduit
	Diameter	3.5-3.6 m
Sand basin	Length of chamber	112 m
	Width	40 m
	Depth	6 m
Conduit-sand basin to HRT intake	Length	1774 m
	Type	Buried steel pipe. GRP-pipe or Concrete conduit
	Diameter	3.5-3.6 m
Headrace tunnel	Headrace tunnel. length	5040 m
	Diameter	5.5 m
	Inclination	6.21%
	Water velocity (rated)	1.33 m/s
	Adit tunnel	510 m
Surge shaft	Diameter of shaft	3.5 m
	Bottom of shaft	1420 m a.s.l.
	Top of shaft	1735 m a.s.l.

	Height of surge shaft	315 m
Pressure shaft	Vertical length	55 m
	Steel lining. length excl. distributor	85 m
	Shaft excavated diameter	3.5 m
	Steel lining. diameter	2.9 m
Powerhouse	Units and installed capacity	3×36 MW
	Type Vertical	Pelton
	Rated speed	375 rpm
	Rated generator capacity	3×45 MVA
	Size of powerhouse (wxlxh)	13.5x71x28m
Powerhouse access tunnel	Length	330 m
	Width	5.5 m
	Height	6.0 m
	Invert	Asphalted
	Portal	Concrete structure
	Portal door	5.0x5.0 m
Cable tunnel	Length	510 m
	Diameter	5.5 m
	Invert	Gravel surface
	Cable supports	Cable ladders
Tailrace tunnel Tunnel	length	500 m
	Tunnel section. horseshoe	5.0 x 5.0 m
Tailrace canal	Length	125 m
	Bottom width	5.0 m
	Normal tailwater elevation	1343.2 m a.s.l.
	Maximum tailwater elevation	1346.4 m a.s.l.

3.1 Headworks

A low concrete spillway dam will be constructed across the Tergi River at an elevation of approximately 1725m a.s.l. There will be a 0.25ha intake pond with a crest elevation of 1729.3m a.s.l. The power plant load will be controlled by the settlement basin water level (which is controlled by the intake pond water level) as the plant cannot take large load fluctuations which could occur due to the small size of the intake pond. The headworks will include sand sluices, a fishpass and an intake structure.

The design maximum discharge for the headworks is 515m^3/s which corresponds to a 200year event. In such an event there should be no damage to the headworks structures. The 1,000 year event provides a check flood value of 660m^3/s, this event may cause minor damage to structures but they will be designed not to fail.

3.2 Spillway Dam

The dam will be a 30m long overtopping concrete structure, i.e. the entire crest will act as a spillway. Downstream of the spillway will be a concrete stilling basin to reduce the energy in the water before it re-joins the river. The river will have further rip rap protection to prevent bed scour. Walls will be built along the sides of the spillway to ensure all the water is directed into the stilling basin.

3.3 Sand Sluices

Two sand sluices will be constructed which can also double as a gated spillway in a flood event. Main function however will be to prevent larger sediments/bedload material from entering the intake. The gates will be controlled by electrical motors which can be operated either locally or remotely. The gates will be 6.4m wide and 6m high. A 2m high concrete wall will guide the sediment and bedload material towards the sand sluices and away from the intake. There will be access provided to remove any build-up of sediment.

3.4 Intake

A conventional concrete intake structure will be constructed next to the sand sluices on the right bank. The intake's sill will be 0.8m higher than the slab in front. There will be 3 inlet openings, each 4m wide and with 2.2m high electric wheel gates. As a backup, each inlet will also have a manually operated bulkhead gate. Trash screens will be situated in front of the gates and in the chamber between the intake structure and the conduit entrance. Sensors will measure the depth and temperature of the water and the information will be relayed to the power plant.

3.5 Conduit to settlement basin

The settlement basin cannot be build close to the intake structure due to the topography and the amount of debris brought to the river by a tributary. A closed conduit 325m long will take the water from the inlet to a settlement basin. This conduit will operate under pressure and flow full at all discharges. Details of the materials used and exact design have not been finalised. Where the conduit crosses water courses extra rip-rap protection will be provided.

3.6 Settlement basin

The settlement basin will be 112m long and 40m wide with two separate chambers. It will be designed to remove particles down to 0.2mm diameter with a design flow of $33m^3/s$. During cleaning, one chamber will operate. Electric gates will control flow to the settlement basin. A flushing gate will be constructed at the downstream end of each chamber, which will convey the flushed sediment to a natural stream and then back to the river.

The water level in the chambers must exceed 3m to prevent air entering the conduit. The load on the powerhouse will be controlled by this level so this will be monitored and controlled from the powerhouse.

A seasonal watercourse is situated at the site of the settlement basin which appears when the snow/ice is melting. A culvert will be built under the settlement basin to accommodate this stream, with erosion protection to ensure it does not undercut the structure.

3.7 Conduit to headrace tunnel

This will be a similar design to the previous conduit and will be 1,758m long. It will be full and under pressure at all discharge rates. The conduit will be buried, but has to cross a gas pipeline. There will be a concrete chamber at the transition between the conduit and the headrace tunnel which will have an air outlet to prevent air bubbles being carried down the headrace tunnel to the powerhouse.

3.8 Headrace tunnel

The headrace tunnel will be 5,042m long, 5.5m wide and will convey water to the pressure shaft feeding the power units. It will be constructed using a tunnel boring machine and it is anticipated that the tunnel will be unlined with local strengthening where required (fault zones) potentially using shotcrete or concrete lining if necessary. Lining will be decided during the construction phase as the tunnel progresses. Once the headrace tunnel is operational the access tunnel used for construction will be plugged, leaving a metal access hatch for maintenance.

Head loss in the tunnel will be small due to the low velocity and smooth walls.

3.9 Surge facilities

A surge shaft will be constructed to reduce water hammer in the headrace tunnel system and to facilitate grid regulation. This will be located 200-300m upstream of the pressure shaft. The top of the shaft must exceed 1750m a.s.l. to prevent overspill in the event of sudden closure at the turbines. The shaft will be either vertical or inclined.

3.10 Pressure shaft

A steel lined pressure shaft will convey the water from the headrace tunnel and then branch into 3 separate tunnels to each of the power units. The branches will be in a horizontal 3m section and will have spherical valves fitted.

3.11 Power House

This will be underground and contain 3 Pelton wheel units. The Pelton wheels will be at 1350m a.s.l. With a net head of 372m and 33m^3/s flow rate, each Pelton wheel turbine unit will have a generator output of 36MW at rated load. The most likely synchronous unit speed for the turbines will be 375rpm with 6 nozzle turbines.

3.12 Tailrace

The final stage is a tunnel taking the water from the power house back to the Tergi River. It will be 500m long, 5m high and 5m wide. It will start with 3 tunnels converging from each turbine. The invert of the tunnel will be horizontal at 1,342.15m a.s.l. At the portal there will be 35m of cut and cover concrete then a short open canal before it enters the head pond of the Larsi project.

4 Hydrology

4.1 Catchment details

The catchment area for the Tergi River above the design section is 806km^2 [4,6]. There are 15 tributaries which join with the Tergi River between the dam headworks and the outlet of the tailrace tunnel (the diversion section). The Kuro, Tibistsqali and Amali rivers are the most significant tributaries in this section[19].

4.2 Available river flow data

Flows in the Tergi River were gauged at Kazbegi (Stepantsminda) Hydrological Watch Point (HWP) from 1928 to 1940 and from 1953 to 1990[3,4,6]. The data provided in the ESIA[3] report are only available up to 1986. Water depths were taken using a depth-stick and a daily average water level was calculated from this. Velocity values were obtained using a hydrometric current meter (readings taken 20-25 times per year) which, when combined with the average daily water depth observations, provide an estimate of discharge rate. Discharge data provided from the periods of observed flow available, was estimated using twice daily observations (8am and 8pm) adopting rules developed by the former Soviet Union[6].

The flow values for the design section, which is further downstream, have been derived using these observations and a scaling factor of 1.029 for all instances. The data used to calculate average annual and average monthly flow rates terminates at 1990, although in the ESIA[3] report these values are only given up until 1986.

The lack of a recent record, from 1990 to the present day, is of importance for proposing an environmental flow regime, as this is the period where climate change signals have become apparent in other regions. Therefore, the present hydrological flow regime for the catchment could differ from the data provided (1928-1940, 1953-1990[3,4,6]). Whilst there is limited evidence that the Caucasus Range and Georgia have been affected by climate change to date[6], there are reports of increased winter discharge, decreased summer discharge, the general increased frequency and duration of precipitation events and the increased trend of precipitation volume[4].

Arup has not been provided with access to the raw data and it is therefore not possible to provide independent verification of the accuracy of the analyses outlined below. In general, some ambiguity surrounds the way that hydrological data are presented in the available reports. This has been addressed and acknowledged where possible.

[19] Brief Hydrological Description of Tributaries Existing on the Dariali HPP Diversion Section; “Gamma” note as sent by Dariali Energy on 08/12/2013

4.3 Average annual flow rates

Analysis is based on 51 years (1928-1940 and 1953-1990) of discharge data from Kazbegi HWP. Statistical processing using the moments method generates a distribution curve and a scaling factor of 1.029, derived from the expansion of the catchment area produce estimates for average annual flow for the design section.

Table 2[4,6] provides baseline data for the Tergi River, including catchment area, average annual flow rates and flow exceedence probabilities. This table identifies average annual flow rates at the Dariali dam as 25.4m^3/s, with a Q_{95} (flow exceeded 95% of the time) value of 16.4m^3/s. Q_{10} (flow exceeded 10% of the time) for the headworks is 33.4m^3/s, which is the approximate design intake flow rate for the Dariali HPP station.

Table 2[4,6] Average annual flow rates of the Tergi River at Kazbegi HWP and the design section with different supply discharge, m^3/s

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

4.4 Seasonal variability of flow

Table 3[4,6] is a within-year distribution of the average flow rates for the Tergi River at the design section. This displays average monthly flow rates, obtained from average annual values of the average monthly flow rates at Kazbegi HWP, for three flow exceedance probabilities: Q_{10} (high flow), Q_{50} (medium flow) and Q_{90} (low flow), as stated in HPP Project Design[6] report. The proposed rate of environmental flow release remains constant, with 2.54m^3/s [4,6] of water released independent of monthly and seasonal variation of flow.

Table 3[4,6] Within year distribution of the design supply average annual flow rates of the Tergi River in the HPP headworks section.

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

Figure 1, below, illustrates the data from

Table 3[4,6]. This shows the average seasonal variation of flow rates at the design section and the inter-annual variation of flow. The Q_{10} flow rates exceed the Q_{90} discharge by approximately two times on a consistent basis throughout a 12 month cycle. Additionally, **Figure 1** illustrates the maximum designed flow rate (red dashed line) for the Dariali HPP station, which is 33m^3/s [4,6]. All discharge rates in excess of this threshold will flow over the spillway, and through the fish pass, at the dam.

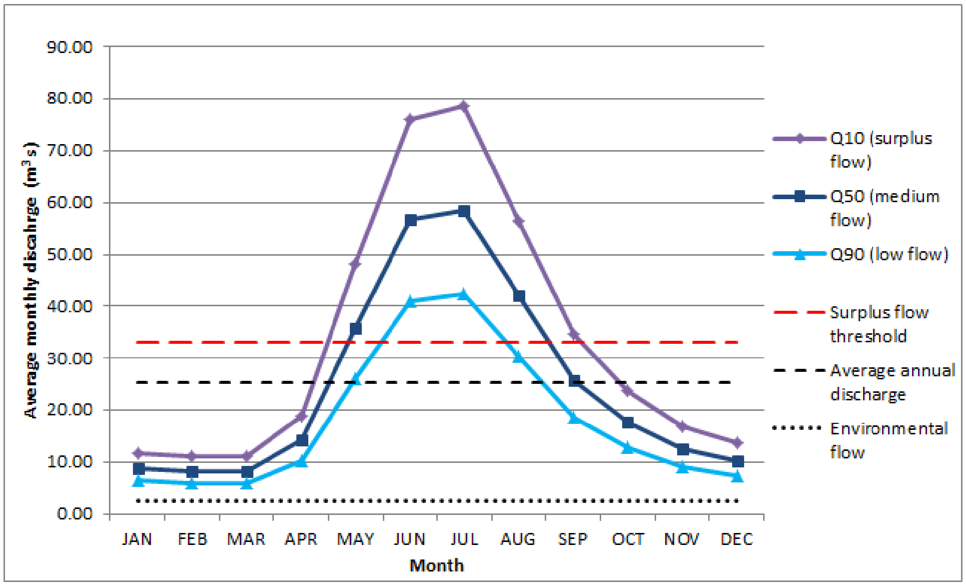


Figure 1 Monthly flow rate variation in the Tergi River at the design section with differing supply rates

Table 4[6] and **Figure 2** present an analysis of estimated flow rate variation within months for the Tergi River at the design section. The 51-year, non-continuous dataset used for this dates from 1928-1940 and 1953-1990[3,4,6] and is agreed throughout the reports. However, in the HPP Project Design[6] report an additional date range of 1928-1975 is given. It is not clear where this date range has arisen from, or whether this is a mistake within the HPP Project Design[6] report. This has not been verified.

Table 4 is taken directly from the Dariali Hydroelectric Project – Project Design Report[6] and shows flows in 10-day sections, with an average flow rate for each 10 day period given at Q_{10}, Q_{50} and Q_{90}. On an annual basis, average flow rate is consistently lowest between December-March, increasing rapidly in the melt season (April-June), peaking in July and then progressively decreasing until December.

For a within-month analysis it is immediately apparent that the typical cold, 'winter months' (December-March) show very little variation of flow between the 10-day periods across each flow exceedance probability. However, as the melt season arrives (April-June) there can be large variations of flow rate within months (e.g. Q_{10} – April I = 12.1m^3/s and April III = 30.1m^3/s; approximately a three-fold difference). A less pronounced difference in flow rate is also evident as discharge rates begin to reduce (e.g. Q_{10} – September I = 41m^3/s and September III = 28.5m^3/s **Table 4**[6].

Table 4[6] Within-year distribution of the design supply average annual flow rates of the Tergi River in the design HPP headwork section pursuant to 10 days.

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

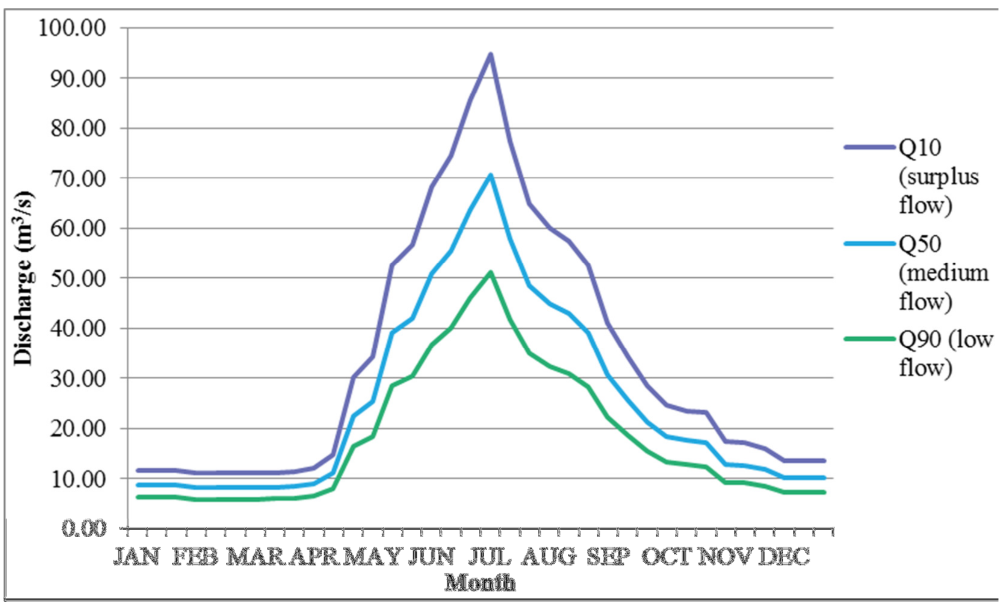


Figure 2 10-day average discharge at the Dariali intake

Figure 3[6] is a flow exceedance curve for the Kazbegi HWP. Based on **Figure 3**[6], average annual flow rates of 24.7m^3/s are achieved at approximately Q_{37}. Q_{50} has discharge of approximately 16m^3/s and Q_{95} is estimated to be 7m^3/s. However, these Q_{50} and Q_{95} values differ significantly from those estimated in **Table 2**[4,6] and the Technical Due Diligence[4] and HPP Project Design[6] reports, with values of 24.2m^3/s and 15.9m^3/s respectively. The data in **Table 4** provide an indication of inter-monthly, and inter-seasonal variation in flows and allow greater interpretation.

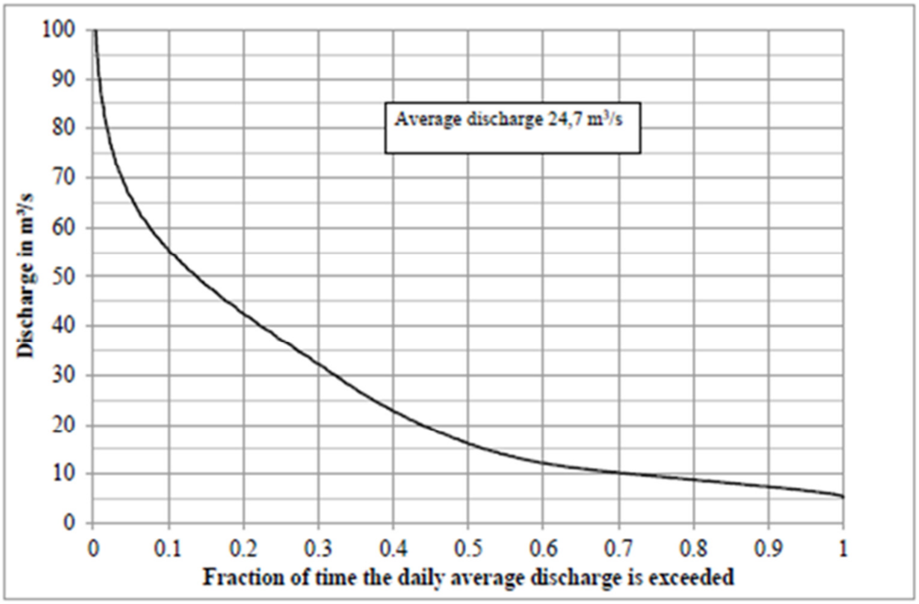


Figure 3[6] Flow exceedance curve for discharge at the design section

4.5 Operation of Dariali HPP

Operation of Dariali HPP will have a significant impact upon flow rates in the Tergi River. For example, the estimated peak flow rate range will reduce from approximately 51m^3/s and 95m^3/s for Q_{90} and Q_{10} flow rates respectively, to 21m^3/s and 65m^3/s. Of most significance will be the impact on discharge rates during the winter period, when approximately 70% of the flow will be abstracted under average flow conditions. These impacts are illustrated in **Figure 4**, **Figure 5** and **Figure 6**.

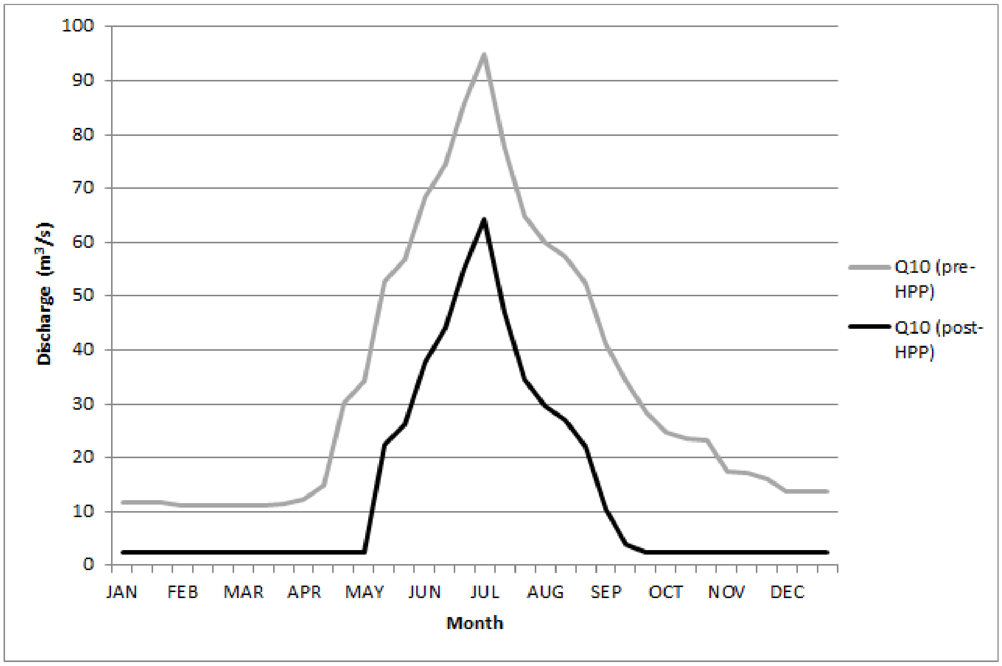


Figure 4 Seasonal flow variation in the diversion section for Q_{10} discharge rates for 10 day periods throughout the year. Grey line indicates average Q_{10} discharge rate; black line predicts the impact of Dariali HPP on Q_{10} discharge rates.

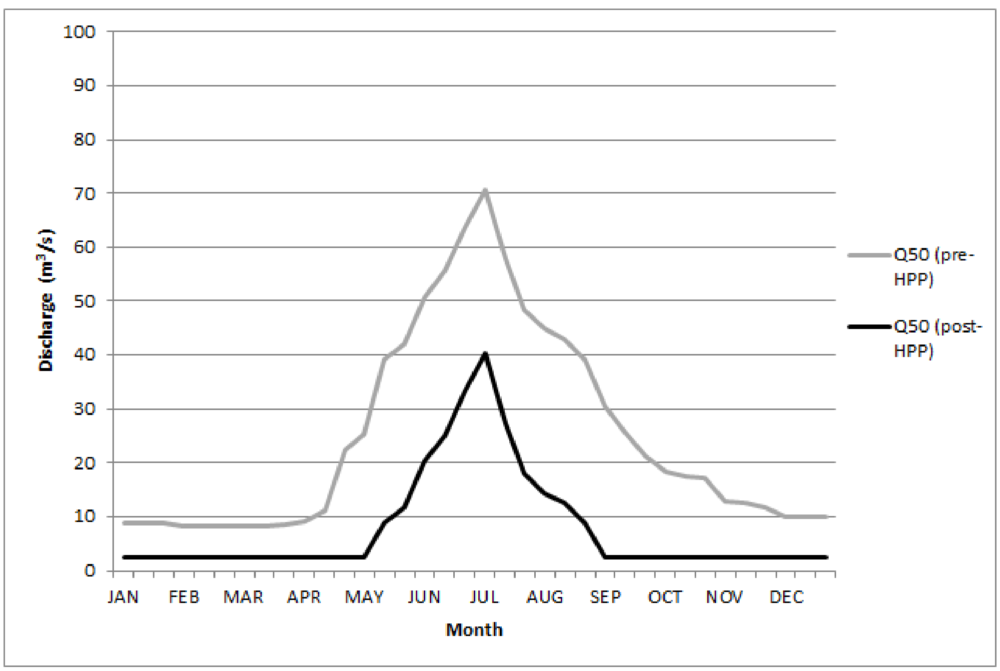


Figure 5 Seasonal flow variation in the diversion section for Q_{50} discharge rates for 10 day periods throughout the year. Grey line indicates average Q_{50} discharge rate; black line predicts the impact of Dariali HPP on Q_{50} discharge rates.

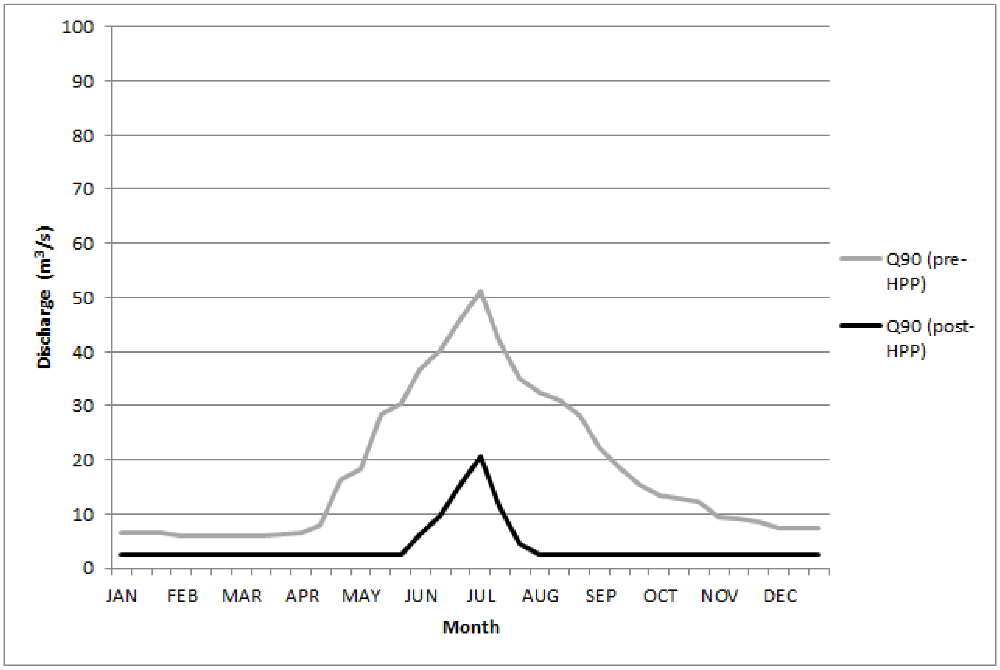


Figure 6 Seasonal flow variation in the diversion section for Q_{90} discharge rates for 10 day periods throughout the year. Grey line indicates average Q_{90} discharge rate; black line predicts the impact of Dariali HPP on Q_{90} discharge rates.

Figure 7 shows the projected impact of Dariali HPP operation upon Tergi River flow in the impacted section. The figures have been calculted using within-month values for average Q_{50} flow obtained from Kazbegi HWP. During winter months there is an approximate 70-75% decrease in Tergi River discharge, whilst peak flows in summer months will be reduced by approximatley 40%.

The greatest proportionate impact upon flow conditions would occur during the early-mid melt season (April and May) and the end of summer / early autumn (September and October). Similarly, at the end of summer and early autumn the normally progressive decrease in Tergi River discharge rates would be accelerated. Both of these periods could see Tergi River flow reduced by approximatley 90%, and would thus be of most significance for any fish migration that may occur during these times.

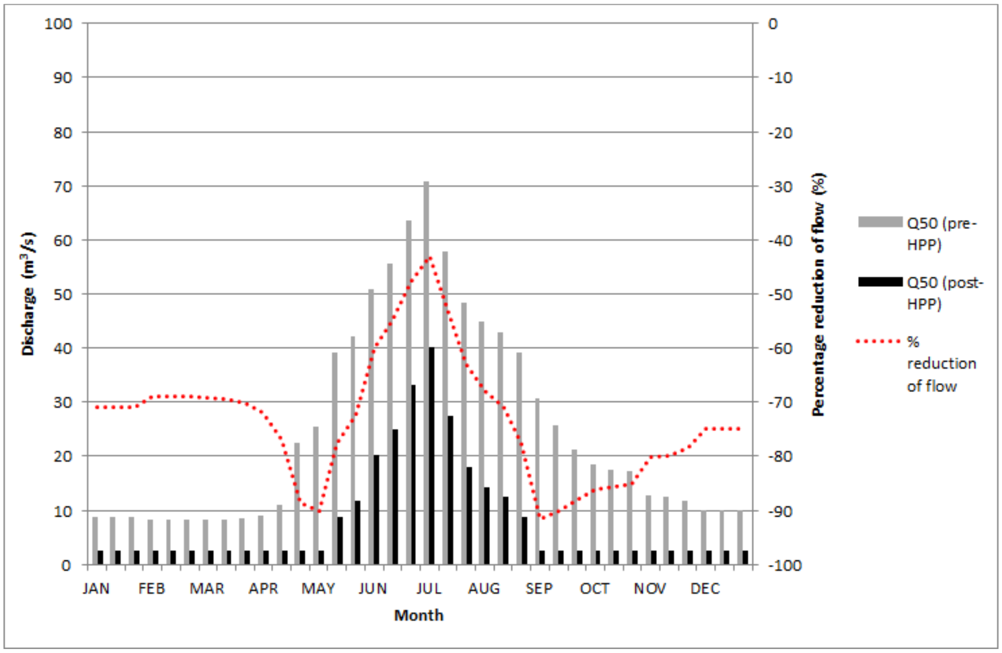


Figure 7 The impact of Dariali HPP operation upon flow regimes in the Tergi River diversion section for a typical year (within-month average Q_{50} flow). The red dashed line indicates the projected reduction of discharge following Dariali HPP operation as a percentage from pre-HPP Tergi River flow.

4.6 Maximum discharge

Average perennial maximum flow rates have been extrapolated for the design section from the Kazbegi HWP using the same conversion factor as for average annual flow rates. Average perennial maximum discharge is estimated to be approximately 140m^3/s [6] (**Table 5**[4,6]). The maximum observed flow rate at the Kazbegi HWP is recorded as 481m^3/s in 1967[3].

Table 5[4,6] Differing discharge rates for flood recurrence events of return period *P* (listed as τ in **Table 6**[4,6]) for maximum flow rates of the Tergi River, m^3/s.

Section	km²	Method	QQ_0 m³/s	Cv	Cs	δ	Supply P%						
							0.1	0.5	1	2	3	5	10
Kazbegi HWP	778	moments	130	0,55	2,20	71,5	595	445	385	345	300	260	215
		graphic-analysis	137	0,59	2,30	80,7	645	505	440	380	345	300	240
Design K=1,018	806	moments	132	-	-	-	605	455	390	350	305	265	220
		graphic-analysis	140	-	-	-	660	515	450	390	350	305	245

Table 6[4,6] lists the maximum water levels of the River Tergi. Flow values for Q_{10} and greater are listed, all of which exceed the level of the bank (Q_{10} = 1.75m above the bank level at the design section).

Table 6[4,6] Estimated water levels of the Tergi River for a varying degree of flood events. Cross section 2 is sited at the location of the Dariali HPP headworks.

Cross-section N	Distance between cross section, m	Water levels, m asl	Bottom lowest levels, m asl	water levels, m asl				
				τ = 200 a, Q=515 m^3/s	τ = 100 a, Q=450 m^3/s	τ = 50 a, Q=390 m^3/s	τ = 20 a, Q=305 m^3/s	τ = 10 a, Q=245 m^3/s
1	30	1728.80	1728.03	1731.20	1731.00	1730.80	1730.50	1730.30
2	90	1726.35	1725.35	1729.20	1729.00	1728.70	1728.40	1728.10
3	90	1722.55	1721.50	1725.40	1725.20	1725.00	1724.60	1724.40
4	135	1719.25	1718.33	1721.90	1721.70	1721.40	1721.10	1720.80
5	75	1710.88	1710.35	1712.60	1712.40	1712.20	1712.00	1711.80
6	90	1705.28	1704.53	1707.50	1707.30	1707.10	1706.80	1706.60
7		1697.75	1696.95	1700.00	1699.90	1699.70	1699.40	1699.20

4.7 Minimum Discharge

Average perennial minimum discharge has been extrapolated for the headworks section from the Kazbegi HWP. Average annual minimum discharge rate for the site of the HPP headworks is 7.34m^3/s [6]. The lowest recorded discharge at the Kazbegi HWP was 4.00m^3/s in 1938[3].

Anecdotal information from Dariali Energy reports the Tergi River does not freeze completely having only encountered one significant winter freeze event in eighty years.

4.8 Tributary contributions

Between the dam headworks and the outlet of the tailrace tunnel there are 15 smaller tributaries which join the main channel of the Tergi River[19].

The discharge contribution from these smaller tributaries varies throughout the year, demonstrating a similar within-year distribution of flow rate as that for the Tergi River. **Table 7**[19] and **Figure 8** below detail the extent of contribution from these tributaries. The majority of the classified tributaries contribute less than 0.3m^3/s to the Tergi River during the summer months, with the River Amali, left tributary #4 (**Table 7**[19]), contributing greater than 50% of the total combined tributary discharge in the diversion section.

During the peak months for flow rate (July and August), average combined contribution to the Tergi River is approximately 8.3m^3/s, whilst during the winter months, where lowest flow is experienced, average flow rate reduces to 1.14m^3/s. The average annual contribution to the Tergi River from these 15 tributaries is 3.27m^3/s. Thus, this flow will be in addition to the proposed environmental flow to be released from the headworks (at present, 2.54m^3/s).

However, significant caution should be used when referring to Tergi River flow in the diversion following HPP operation as a combination of tributary and environmental flow, owing to several factors. The location of each of the tributary confluences is not clear, neither is the distance from their confluence with the Tergi River to either the HPP headworks or the outlet of the tailrace tunnel specified. Furthermore, there is no data available regarding subsurface flow patterns in the diversion section, either to or along the Tergi River. Consequently, it is not known which sections of the Tergi River channel in the diversion section will benefit most from these contributions. Therefore this value is only applicable for the section of the river immediately upstream of the tailrace tunnel outlet.

Table 7[19] Discharge contribution to the Tergi River from tributaries between the dam headworks and the tailrace tunnel outlet

# of the river or the valley	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Ave.
Right tributaries (m^3/s)													
#1. Riv. Kuro.	0.12	0.12	0.13	0.17	0.29	0.47	0.87	0.86	0.46	0.26	0.19	0.16	0.34
Valley #2	0.02	0.02	0.02	0.03	0.05	0.08	0.15	0.15	0.08	0.04	0.03	0.02	0.06
Valley #3	0.02	0.02	0.02	0.02	0.04	0.07	0.13	0.13	0.07	0.04	0.03	0.02	0.05
Valley #4	0.00	0.00	0.00	0.00	0.001	0.001	0.002	0.002	0.001	0..001	0.00	0.00	0.001
Valley #5	0.03	0.03	0.03	0.04	0.08	0.12	0.23	0.23	0.12	0.07	0.05	0.04	0.09
Valley #6	0.02	0.02	0.03	0.04	0.06	0.10	0.18	0.18	0.09	0.05	0.04	0.03	0.07
Valley #7	0.03	0.03	0.03	0.04	0.08	0.12	0.23	0.23	0.12	0.07	0.05	0.04	0.09
Valley #8	0.04	0.04	0.04	0.06	0.09	0.15	0.28	0.28	0.15	0.08	0.06	0.05	0.11
Valley #9	0.01	0.01	0.02	0.02	0.03	0.06	0.10	0.10	0.05	0.03	0.02	0.02	0.04
Valley #10	0.01	0.01	0.01	0.01	0.02	0.03	0.05	0.05	0.03	0.02	0.01	0.01	0.02
Valley #11	0.01	0.01	0.01	0.01	0.02	0.03	0.05	0.05	0.03	0.02	0.01	0.01	0.02
Left tributaries (m^3/s)													
Valley #1	0.06	0.06	0.06	0.08	0.14	0.22	0.41	0.40	0.22	0.12	0.09	0.08	0.16
#2. Riv. Tibistsqali	0.16	0.16	0.18	0.24	0.40	0.65	1.20	1.19	0.64	0.36	0.26	0.22	0.47
Valley #3	0.03	0.03	0.03	0.04	0.07	0.11	0.20	0.20	0.11	0.06	0.04	0.04	0.08
#4. Riv. Amali	0.58	0.58	0.63	0.82	1.41	2.28	4.22	4.17	2.23	1.26	0.92	0.78	1.65

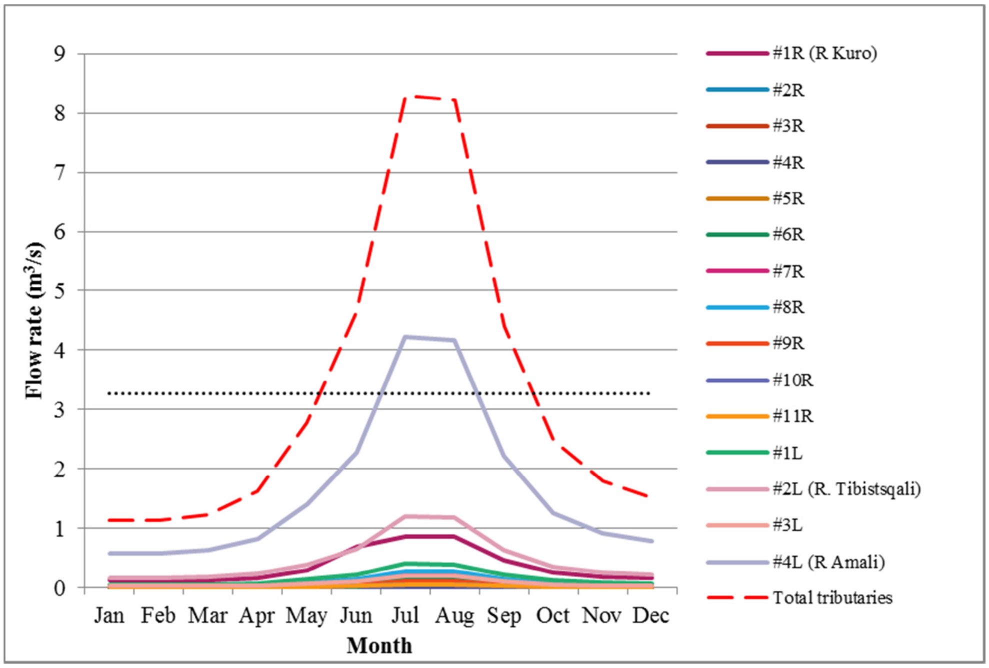


Figure 8 Annual flow contribution from the tributaries to the Tergi River between the dam head works and the tailrace tunnel outlet.

4.9 Sediment regime

Solid runoff was observed for the Tergi River at Kazbegi HWP between 1928-1940[4,6]. This data yields an average solid discharge during this period equal to 24.1kg/s [4,6], equivalent to 975g/m^3 [6], although it is not specified in the existing information whether this relates to suspended solid sediment or coarse bed sediment.

The reliability of this data is not certain and this is reflected in the high coefficient of variation upon analysis of results[4]. This is due to the imprecision and lack of suitable devices available to accurately measure suspended solid load and coarse bed sediment transport.

Mudflows and debris flows are reported to be a common feature of the tributaries in the Tergi River catchment[3,4,6,19]. Whilst the frequency of these events can vary, reports suggest events tend to occur on an approximate 2-3 year cycle[19], with sediment accumulating in sufficient quantities in the tributary valleys before being transported. These processes deliver large quantities of sediment to the Tergi River channel, which is then transported further downstream.

4.10 Groundwater and sub-surface flows

Groundwater has been identified in quaternary deposits, although no long-term monitoring has been completed[4]. Anecdotal information gained from Dariali Energy has suggested that the Dariali HPP station will not be founded to bedrock, which will permit groundwater and sub-surface flows through the floodplain to continue.

5 Baseline Geomorphology

5.1 Introduction

Fluvial geomorphology is the scientific study of rivers and the processes that shape them. An understanding of the complex interactions between catchment management, river flow, sediment transfer, sediment storage and channel form is fundamental to an assessment of aquatic habitat biodiversity. In order to gain a better understanding of the fluvial geomorphology of the River Tergi, local to the proposed dam site, a visit was conducted by an experienced fluvial geomorphologist, Dr David Hetherington. The site visit is described below followed by a brief overview of the geomorphology of the local river system.

5.2 Site Visit

The site was visited on the Afternoon of Wednesday the 11th December, and on the morning of Thursday the 12th of December 2014. The weather on the both days was cold (around -15C) and dry, with changeable levels of cloud. The discharge on the site was estimated as being between $10m^3/s$ and $14m^3/s$ (based on a 12m-wide, 1m deep flow of around $1ms^{-1}$ in the single thread channel just downstream of the proposed location of the Dariali Hydropower Plant headworks). A drive-over survey was conducted and specific locations were observed in more detail (notably around the headworks site, and around significant tributaries).

5.3 System Geomorphology

5.3.1 Overview

In natural systems rivers exist in a state of dynamic equilibrium as they transfer water and sediment through the catchment and adapt to constantly changing hydrology, sedimentology, ecology and downstream conditions. This state results in transient diversity over many spatial scales, which all change over different temporal scales. This dynamic complexity provides a unique and sensitive habitat that numerous important indigenous species have evolved in over geological time. A thorough consideration of geomorphology is important with regards to understanding habitat conditions and how they might react to change.

The River Tergi flows through the Caucasus Mountains, on the western boundary of the Kazbegi National Park. In the vicinity of the proposed Dariali Hydropower Scheme the river is surrounded by steep mountainous slopes, which vary with regards to the level of vegetation present. In winter (December to February) precipitation predominantly falls as snow, which holds much water in the catchment. Flows tend to peak in the warmer summer months as snow and ice melts, which can be increased further by additional rainfall and/or sub-glacial releases. In summer months it is likely that the River Tergi will be subject to diurnal fluctuations in discharge in response to daytime snow and ice melting during peak sun hours, and overnight refreezing. This will result in an late afternoon/ early evening daily peak flow, and daily low flow in the morning soon after sunrise.

Fifteen notable tributaries flow into the River Tergi between the Dariali headrace (tunnel inlet) and tailrace (tunnel outlet). Eleven of these are from the East (right), and 4 are from the west (left). The most significant of these tributaries are the Rivers Kuro, Tibistsqali and Amali. The tributaries are known to be prone to large, and sometimes catastrophic debris flows towards the Tergi River once local storage thresholds are passed. These debris flows have the potential to disrupt fluvial processes within tributaries and the main channel and exert blockages and localised changes in energy levels.

The geology of Kazbegi District mainly comprises Palaeozoic shales and Jurassic limestone and marl together with igneous rocks. It is understood that arisings from tunnelling operations have mainly consisted of shales and granite. The main soils in the region are mountain-meadow type (shallow brown earths).

The system is sediment rich, with much material being delivered from the local steep slopes after being made available from a number of processes including freeze-thaw weathering, fluvial and pluvial erosion, ice movement and vegetative development. In addition to sediment provision by contemporary processes, much fluvio-glacial sediment is also available locally in the form of extensive eroding terrace features left after previous glacial retreats and outwash floods. These terrace features flank the river in the vicinity of the proposed Dariali headrace site, and their steep, high slopes will provide a large and constant supply of water-worked cobbles and boulders, and glacial fines and sands.

The rich sediment supply has resulted in a system that is diverse between reaches as energy levels and sediment transport potential varies from deficit to surplus. This has resulted in a river system that alternates sequentially between steep boulder rapids, lesser graded single-thread and low gradient multi-channel forms. The location of these reach types will also be part-controlled by surface geology and topographic constraints. The dominance of the wide-floodplain, multi-thread type channel form between the Dariali headrace and Tailrace would suggest that the system is dominated by deposition (I.E sediment delivery is in exceedance of the available sediment transport potential of the Dariali Regime). In light of this state, it is suggested that large floods are key to ensuring the continued movement of sediment down the system, and maintenance of channel form and fine-sediment-free river bed surfaces.

5.3.2 Channel Form and Process

Around 700m upstream of the proposed location of the Darliali Hydropower plant the river flows through multiple sinuous channels across a wide, flat, low-gradient floodplain. The river in this area would provide excellent habitat for fish due to its hydraulic, sedimentological and morphological diversity. An example of this area is shown in **Figure 9**. A slightly larger, primary channel appeared to flow through the centre of the floodplain in this area.

Figure 9 The Tergi River around 700m upstream of the proposed Dariali Hydropower site.

Downstream of the area shown in **Figure 9**, the river heads into a single thread channel as it passes through the town of Stepantsminda.

The proposed location of the Dariali headrace is shown in **Figure 10**. In this location the channel skirts around a steep eroding terrace feature and is around 10-14m wide, around 1m deep and is dominated by glide and run type flow units. A small lateral step and rapid marks a point where the river channel steepens and enters a boulder-dominated, relatively steep section of river where the flow splits between larger particles (as shown in **Figure 11**).

Figure 10 The proposed site of the Dariali HPP head race. The headrace will be located to the right of the image, and the settlement tanks will be located on the terrace feature in the centre of the image. The river here is single-thread as it skirts around the terrace, before entering a steeper, relatively high-energy boulder bed section.

Figure 11 Downstream view of the relatively steep boulder bed section, towards the relatively shallow-gradient braided section on the distance.

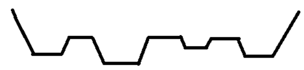
The relatively steep boulder influenced section flows for around 300m down towards a more open floodplain where the river then splits between multiple channels. This braided section extends for around another 1km northwards before the river takes a sharp turn and is flows through a single thread channel again.

The steep boulder rapids, lesser graded single-thread and low gradient multi-channel forms all have different channel sizes, gradients, sediment sizes and general morphology. Changing discharge will have different and complex hydraulic effects according to the type of morphology present at a given location. Thus, the impacts of reduced flow in each type of reach system need to be considered.

5.3.3 Morphology and flow types

The broad different types of channel morphology that are present within the impacted reach have been summarised in **Table 8**, alongside schematics showing how a minimal environmental flow might look within the channel form. The approximate locations and extents of these 3 general channel types is shown in **Figure 12**.

Table 8 General channel types within the impacted reach downstream of the Dariali head race.

Channel Attribute	Single thread	Boulder Rapids	Multi-Channel (Braided)
Relative Gradient	Moderate	High	Low
Bank Height (bed to bank full)	Approximately 1.5m	Approximately 1m	Approximately 0.5m
Channel width	10-14m	8-16m	4-6m per channel.
Shape			
Normal Flow			
Min Env Flow			
Potential Impact of reduced ecological flow	Low	Moderate	Moderate-High

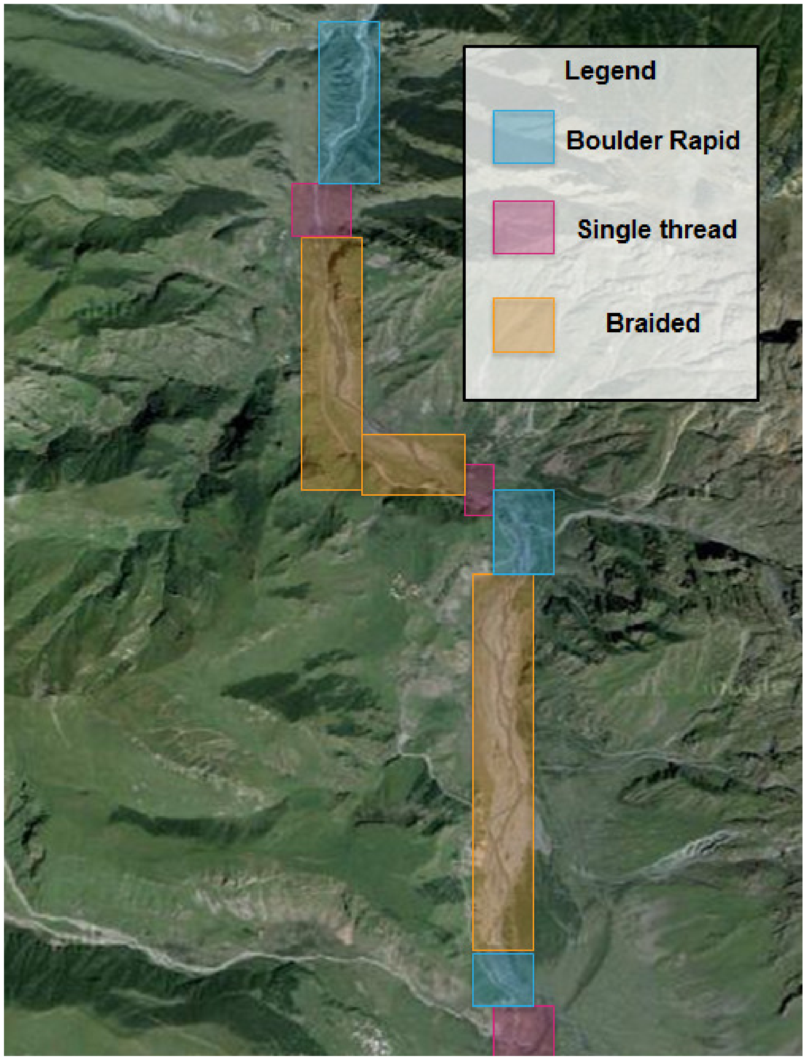


Figure 12 Approximate locations and extents of the 3 general channel types on the Tergi River in the impacted reach downstream of the Dariali head race.

5.3.4 Single -thread channel sections

The single thread sections of channel typically range between 8 and 12m in width, and are dominated by run-type flow units. It is estimated that during “normal” winter flow conditions (such as on the day of survey) the velocities were around 1 – 2ms^{-1}. The dominant bed material within most of the single thread sections was cobbles, with larger boulders influencing flow sporadically. Typically, bank height was relatively low and graded into the channel, indicating that channel width and depth would reduce together with decreasing discharge. This should help to maintain passable conditions during low flows.

5.3.5 Steep Boulder Rapid sections

Typically, the relatively high gradient boulder influenced sections exhibit a split flow through exposed boulders, although a primary channel is evident for much of the time in a deepened part of the channel where a reduced flow would accumulate and flow during lower flows. There will be instances where flow does split at low flows, but this should only be the width of the largest boulders in the channel (some of which were as big as $4m^3$).

The presence of meso-topographic bedforms (as shown in **Figure 13**) in the form of boulders in the stoss (upstream) of bigger boulders (>$4m^3$ is size), would suggest that the largest particles of the site have been relatively stable during recent flood events. The meso-topographic bedforms will have the effect of directing flow around boulders during lower flows.

Flow types were dominated by rapids and fast runs, with the occasional lateral pool feature downstream of a large boulder step.

In steep boulder sections it is envisaged that a reduced discharge would flow down a preferential route at the point of the lowest topography, and this should maintain passable conditions during low flows in most instances. However, there may be sections of channel where depths become shallow due to local high gradients, or large steps are created where large boulders influence the river bed of the primary low flow channel.

Figure 13 An example of a meso-topographic bedform just downstream of the Dariali head works site in a steep boulder bed section. The largest boulder in the centre of the photograph is approximately $2m^3$ in size.

5.3.6 Low gradient braided sections

The river channel splits in areas of geomorphological instability due to low gradient and excess sediment supply. In these areas the individual river channels contain a portion of the flow, which can be spread up to 500m away from each other across the floodplain in extreme cases. The individual channels flow at a relatively slow velocity due to the low gradient, and are dominated by riffle, run and glide flow units during "normal" winter flow conditions such as those observed during the field survey. The bed material in such sections is dominated by large and fine river gravels, due to the rivers reduced capacity to transport sediment over the relatively wide floodplain and low gradient. Typically, a larger primary channel could be observed in the multi-channel sections, which should carry a larger proportion of the discharge during low flow conditions. However, there may be instances were channels have similar bed levels and dimensions, which may deplete the ecological value of low flows if they are shared between channels.

According to Friend and Sinha [20] braided channel systems are strongly influenced by the availability of bed-load sediment and width-depth ratios and mean grain size of the bed material are closely correlated with channel pattern. Richards *et al.* (1993)[21] discusses the behaviour of individual channels within a braided reach and suggests that they have characteristics that reflect the proportion of total system discharge, suspended and bed-load material that they carry at any time and that a distinction can be made between dominant and secondary channels. The characteristics of this dominant channel are dependent on local sediment supply and stream power conditions. The dominance of a channel will switch over time. As the dominant channel carries the main flow and sediment load, it will start to aggrade and becomes perched, it will then lose flow as its capacity is reduced and the discharge is diverted to a lower secondary channel. The patterns of avulsion and channel switching are discussed in detail by Leddy *et al.* (1993)[22] who state that the temporal and spatial variability of flow discharge (along with sediment) is the ultimate cause of avulsion (switching) within braided channels.
Impact on braided channels as a result of reductions in flow within the physical context of this site is likely to result in the dominance and stability of a single channel during the winter months. By limiting stream power (in the form of reduced flows) and therefore reducing the amount of sediment supply to the river the secondary channels will infill and flows will divert to the dominant channel. The proposed environmental flow will have limited sediment transport ability however; if the dominant (single winter flow) channel starts to agrade then the flow will switch to a secondary channel which will become the dominant single winter flow channel.

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[20] Friend, P. F., and Sinha, R. (1993), Braiding and meandering parameters, in Best, J. L and Bristow, C. S. (eds) *Braided Rivers* Geological Society Special Publication No. 75
[21] Richards, K., Chandra, S., and Friend, P. (1993), Avulsive channel systems: characteristics and examples, in Best, J. L and Bristow, C. S. (eds) *Braided Rivers* Geological Society Special Publication No. 75
[22] Leddy, J. O., Ashworth, P. J., and Best, J. L. (1993) Mechanisms of anabranch avulsion within gravel-bed braided rivers: observations from a scaled physical model, in Best, J. L and Bristow, C. S. (eds) *Braided Rivers,* Geological Society Special Publication No. 75

In summer months where the peak flows are capped, it is likely that more frequent channel avulsion (switching) will occur than does at present, due to the high volumes of sediment entering the system and the slightly reduced capacity of the channel to carry this material downstream of the braided areas. This would result in more sediment being deposited in the braided sections, blocking channels and switching flow dominance and the number of secondary channels. A knock on effect of this may result in some sediment starvation and incision in reaches downstream that have limited sediment supply coming in from bank/slope processes.

Figure **14** and Figure **15** respectively show the large braided section around 300m downstream of the proposed headrace during winter “normal” flow conditions, and in the late autumn when flows will be relatively high. Observation of these images reveals that the system appears to retract to a primary channel for much of the reach. This may mean that the braided reaches do have a general tendency to fill primary channels during low flows, which would increase the habitat function of low environmental flows.

Figure 14 Image showing the large braided section downstream of the Dariali headrace (taken in September 2013).

Figure 15 Image taken in December 2013 from a similar location as the view in **Figure 14**.

5.3.7 Hillslope Processes and Large Floods

The River Tergi exists as a functioning and dynamic river system, in a state of dynamic-equilibrium after prolonged periods of fluvial activity. However, large and catastrophic debris flows have the potential to disrupt the fluvial system, and the maintenance of a naturally-formed fluvial channel. Such large magnitude sediment delivery events are part of the natural geomorphological system, and the presence of the ecology in the system demonstrated that these events are not ecologically catastrophic.

Large floods also have the potential to temporarily change the nature of the river system. In the instance of high magnitude and long duration events, sediment transport may exceed supply which could result in certain reaches being stripped of sediment, with flows becoming deeper and slower. In the instance of high magnitude events being short duration, then large volumes of sediment may be delivered to low gradient areas, which could clog the system and cause increased geomorphological instability. In these instances braided sections could develop more intertwining channels, which could increase the potential for low flows to be split, and increase the potential for habitats created by ecological flows to be reduced in quality.

The unpredictability and size of extreme events may mean that any minimum environmental flow may not provide favourable conditions for fish passage in the short to-medium term as the system readjusts and regains a fluvial form.

6 Aquatic Biodiversity

Survey information on the nature of aquatic ecology (fish, invertebrates and vegetation) for the site is sparse. The ESIA[3] identifies the zonal distribution of fish in the River Tergi and also comments on likely migration and spawning activities and movements.The River Tergi is categorised as a predominantly barbel zone (brown trout, barbel and bleak). According to the ESIA[3], fish in the headwaters of the Tergi River are typically rheophilic (they favour fast-moving water). *Salmo trutta fario* is the only fish species encountered within the designed construction sections[3].

It is thought that the fish prefer to spawn in the Tergi tributaries[23]. The "mountain type" trout can go up to the highest point in the river at 2,000 – 2,500 metres. They build redds in the river gravels where they hide spawned roes (eggs). Climatic conditions are especially severe in the upper part of the river; feed base is poor, which causes decrease of their growing rate and fattening, with delayed sexual maturation.

Comparison with rivers with similar environmental conditions suggests that the fish may spawn in October, before migrating downstream to winter. The eggs will remain dormant during the winter and be safe as long as the river bed does not freeze. Hatching of the eggs might typically occur in June.[24] It is also possible however that fish in such habitats could adopt portioned spawning, where spawning occurs on an opportunities basis, when conditions are favourable, rather than all at once. This behaviour is related to feed base poorness, resulting from a comparative lack of nutrients, and is an adaptation to severe highland conditions.

The ESIA document[3] states that the trout in the scheme area are not thought to undertake long distance migrations, though they make shorter spawning and fattening migrations. Knowledge gathered during the site visit, however, suggests that the fish are thought to migrate as far downstream as the Ezminskaia reservoir in Russia during the winter[25]. The dam at Ezminskaia has no fish pass, meaning that any fish leaving the local system near Dariali will not be able to return back upstream.

Although of least concern in UN general classification, *Salmo trutta* is listed as vulnerable (VU) in the Georgia Red List[26] and it is therefore important that the habitat of the fish is not negatively impacted by the scheme. According to Skeffington *et al*., (2010)[27], it may be one of the freshwater fish species most negatively affected by climate change.

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[23] Bukhnikashvili, A, Kokosadze, T and Gioshvili, M, 2013. Dariali HPP Project Area and Compensation Sites Comparative Analysis: Zoological Component
[24] Personal communication, Professor I. Cowx, University of Hull
[25] Personal communication with EBRD and Dariali Energy representatives.
[26] Status Review of the Biodiversity Conservation in the Caucasus: Achieving C2010 Goals (Georgia) @ http://countdown2010.net/caucasus/
[27] Skeffington, R.A., Wade, A.J., Whitehead, P.G., Butterfield, D, Kaste, O, Andersen, H. E., Rankinen, K and Grenouillet, G., 2010. in *Climate Change Impacts on Freshwater Ecosystems*. Ed. Kernan, M, Battarbee, R.W. and Moss, B. John Wiley & sons Ltd., Chichester

The key attributes of *Salmo Trutta* (*salmonidae*), based on data from International Union for the Conservation of Nature (IUCN), are as follows:

- **Size**: length up to 500mm, weight up to 2kg, but in mountain streams they are generally much smaller than this.
- **Habitat**: Cold streams, rivers and lakes. Well-oxygenated streams. Spawns in rivers and streams with swift water. Spawning sites usually characterised by downward movement of water into gravel.
- **Biology**: Spawns in couples between late October and March. Females select spawning sites and deposit their eggs in the redd. Both sexes usually survive spawning and anadromous trout migrate back to sea or lake in autumn or over winter in rivers and migrate in spring. Fry usually emerge from gravel between March (Spain) and July (Finland). Smolts start to migrate downstream in April-May when temperature increases from low winter level, reaching beyond 5-11°C; migration peaks at rising water levels with increased turbidity.
- **Capacity to pass obstacles at fish ladders**:
    - 2 to 3 meters at a velocity of 2.5 m/s
    - 5 to 6 meters at velocities of 1.8 m/s to 2 m/s
    - Around 10m at water velocities of 1.2 to 1.5 m/s.
- **Minimum depths:** IUCN guidance is not available on the minimum depth of water required by *salmo trutta fario.* The UK Fish Pass Manual recommends a minimum depth of 115mm in baffled fish passes; 300-400mm in a rock ramp type fish pass. Trout are likely to be able to swim in very shallow water of this kind, but the risk of predation becomes very high and the fish rely on shelter available within deeper pools along the course of a river.

7 Impact Assessment

7.1 Hydrology

Average annual flow rates at the design section have been estimated to be 25.4m^3/s. This average masks a significant difference between high and low flows in the summer and winter months. Temperatures drop during the winter months (October-March) and sub-glacial waters will be more prone to freezing. The average flows in the river between January and March are less than 12m^3/s. The spring thaw causes flow to increase for several months, peaking in July-August, before progressively tailing off with the arrival of autumn and winter.

A minimum environmental flow release from the spillway dam headworks of 2.54m^3/s (10% of the average flow) is currently proposed. The proposals will therefore have a significant impact on discharge rates in the Tergi River during the winter months.

In the summer months, the proposed environmental flow forms a much smaller component of the overall river flow. The abstractions, of up to 33 m^3/s, will form a significant component of the flow in the river.

The impact on mean flood flows will be of a lower magnitude, but still appreciable at about 24%.

15 tributaries join the Tergi River channel between the dam headworks and the tailrace tunnel outlet. Flow rates for the tributaties will have a similar seasonality to them. This discharge from tributaries will be in addition to the environmental flow in the Tergi River, although these suggested tributary discharges should be treat with caution as certain tributaries could be reduced due to partial, or in extreme cases, total freezing.

Whilst there is a relatively extensive hydrological record for the Tergi River, stretching over 51-years, there is no data from 1990 to the present day. The impacts of climate change on this region during this period are unknown. Flow measurements are now being taken on the Rivers Tergi and Chxere, and will be important to on-going planning and adaptive management.

7.2 Geomorphology

7.2.1 General

The proposed operation of the Dariali HPP has the potential to impact on the morphology of the Tergi in a number of ways relating to fine and course sediment transport and storage, and resulting changes to morphology. This section explains these potential impacts in the context of how environmental flows function within the local morphology and how this might affect habitat diversity.

7.2.2 Fine Sediment

The local system at the Dariali site, and downstream is very rich in terms of availability and provision of fine sediment. This fine sediment is provided from a number of sources including large remnant fluvio-glacial terraces, erosion of river banks and debris flow deposits and from active glacial and ice erosion at higher elevations.

The available hydrological data for the site suggests that mean summer flows will be reduced by approximately 50% due to the HPP operation. During low flow conditions (predominantly in the winter months), the majority of the flow will be taken into the HPP tunnel. Sediment accumulating in the settlement basins will be periodically flushed back into the system. It is suggested that the summer flows should be capable of transporting fine sediments downstream. The proposals will not change the overall budget in the system. However, flushing of the sediment basins has the potential to change the timing of delivery and location of fine sediments to downstream reaches.

It is recommended that the fine sediment basins are not flushed during the winter, when river flow may not be sufficient to distribute the sediment through the system. The volume of sediments held in the settling pond is unlikely to be significant compared to the volumes of fine sediments naturally available within the system during summer high flow periods. It is envisaged that fines may be deposited in floodplain and wider channels as high flows recede, but a majority of sediment will be washed through the primary fluvial channels and not pose a significant additional threat to the availability of spawning gravels.

However, the impact (before and after) the first release should be observed and considered as part of any on-going adaptive management if needed (potentially during the first geomorphological monitoring survey) In particular, evidence of spawning-grade gravels (and potentially fish eggs) being smothered by fine sediment would be grounds for concern, particularly in braided sections.

7.2.3 Coarse Sediment

The Dariali HPP scheme will be designed so that coarse gravels will be able to be transported down the system during high flows. This is achieved via the opening of gates that can be pulled up from the river bed, which will allow coarse particles to move downstream. This may happen in an initial pulse if coarse sediments have accumulated upstream of the gates.

The operation of the Darial HPP will reduce flows in the summer months by approximately 33 m^3/s. The reduced flow means that there is an increased potential that these coarse sediments could be deposited more readily in relatively low-gradient sections downstream of the HPP. Specifically, this may impact on the braided channel sections in the low gradient reaches.

It should be noted that the highest / most-extreme floods in the catchment will not be represented in the available monthly and 10-day average hydrological data. The highest flood flow on record is approximately 481 m^3/s, which is significantly above the intake flow rate at the Dariali Head Race (of approximately 33m^3/s). Extreme flood events should still have the capability to transport the available coarse sediment in the system.

Because of this, the overall impact of the Dariali HPP station on coarse sediment transport over the regime is difficult to predict precisely. This provides further justification for morphological monitoring soon after operation, and in the years following the scheme's activation.

7.2.4 Morphology

There are a number of potential morphological impacts that could occur at on the impacted reach once the Dariali HPP is in operation. These impacts, and their potential consequences, should all be considered as part of an adaptive management plan.

A key impact on river morphology will be felt in relatively low-gradient, wide-floodplain sections. There is potential that the braided reaches could become relatively sediment starved due to the reduced high flows and associated reduction in sediment delivery. Sediment starvation in braided systems can result in system simplification as primary channels as excess energy that would usually be used to transport sediment, is use to scour and form channels. This can result in secondary channels filling with sediment over time and potentially becoming vegetated. Simplified river reaches that more closely resemble single-thread channel forms would be less susceptible to negative impacts of environmental flows. Such changes could reduce the overall amount and diversity of available river habitat, but may be beneficial with regards to the ecological function and in-channel connectivity of environmental flows in braided sections.

Morphological impacts may be experienced downstream of the Dariali tailrace should reduced flows result in a significant reduction in sediment delivery. This may result in channel simplification and sediment removal in this area.

7.3 Winter flow channel hydraulics

Initial hydraulic analysis of the different channel forms has been undertaken using the Manning equation (see **Table 9**). The data used in the analysis is based on estimates taken from observations made during the geomorphological site visit on the 11th and 12th December 2013. An appropriate value for *n* (roughness) has been selected based on the sediment sizes noted whilst on site. The results should therefore be considered indicative only.

Table 9 Hydraulic analysis of the 10% ($2.5 m^3/s$) environmental flows in the typical different channel forms found in the impacted reach. Calculated values are shown in **bold**, and likely upper and lower limits that account for uncertainties in width and estimated flow rates are provided in brackets.

Channel Type	Estimated gradient	Assumed Manning 'n' value	Other assumptions	Indicative water depth (m) ($12m^3/s$)	Indicative water depth (m) ($2.5m^3/s$)
Single	0.02 to 0.004	0.04 - gravels, cobbles, and few boulders	Full discharge down single channel – reduced cross-section width by 1/3 to allow for boulder coverage	**1**	**0.40m** (0.36-0.44m)
Boulder	0.19 to 0.015	0.05 - cobbles with large boulders	Reduce channel cross-section by 1/2 to allow for boulders	**0.75**	**0.29m** (0.27-0.33m)
Braided	0.09 to 0.016	0.04 - gravels, cobbles, and few boulders	1/2 of discharge travelling down main channel braid	**0.5**	**0.20m** (0.18-0.22m)

Hydraulic analysis shows that water depths could drop below 200mm in braided sections under the 10% environmental flow, assuming that all the flow stays within a single channel. It is important to note that these calculations contain many assumptions and will not take into account any localised morphological variations, which could result in further reductions in water depth in reality.

7.4 Aquatic Biodiversity

The proposals have a number of potential implications for the trout population:

- The dam represents an obvious obstacle to fish migration. Provision of a well-designed fish pass will help to mitigate this impact. This is discussed further in Section 9.
- Lower base flows in the river will affect the depth and extent of aquatic habitat available. This will be particularly apparent on the braided (multiple channel) reaches downstream of the dam. The reduced flow is likely to result in a smaller number of channels, with a consequent reduction in available habitat. If flows are too low, they may be insufficient to form a channel with sufficient depth for the free movement of migrating fish. The risk of predation will also be increased. It is therefore important to establish whether any fish are resident within, or moving along this section of the river, during the winter months.
- The reduction in flows during the winter months will considerably reduce depths of water in the river, as indicated in Section 7.3. Certain areas of The River Tergi and its Tributaries may be more prone to partially freeze around the peripheries and surface in extreme winter conditions. If fish are spawning in these areas, this is likely to damage the roe. A reduced flow also has the potential to result in damaging roe in areas of exposed river bed. It is therefore important to establish whether this reach is used by spawning fish.

8 Environmental Flow Review

The environmental flow for the Tergi River following commissioning of Dariali HPP was calculated using the Tenant (or Montana) method. A value of 10% of the average annual flow rate has been used for defining the minimum release, with the remaining volume of water to be taken by the HPP[4,6]. The proposed environmental flow release rate has been calculated to be 2.54m^3/s [4,6]. The discharge of the 15 tributaries along the diversion section of the Tergi River will be in addition to this flow rate, although this additional contribution is dependent on the locations of each confluence downstream, and the time of year.

8.1 The Montana - Tennant Method

The Montana or Tennant method is a method from the 1970s published by Tennant (Tennant, 1976[28]). It is based on field data obtained in Montana in the United States (USA). It assumes that a percentage of the mean flow is needed to maintain a healthy stream environment. The method is based on the notion that stream width, water velocity and depth all increase rapidly from zero flow to 10% of the mean flow, and that the rate of increase declines at flows higher than 10%[28].

10% of the average flow is considered to be the lower limit for aquatic life. At less than 10% of the mean flow, water velocity and depth would only provide for 'short-term' survival of aquatic life. 20-30% of the average flow is considered to be the flow that would provide satisfactory stream width, depth and velocity for a 'baseflow regime'. The assessment of the environmental quality of different levels of flow is based on the quality of the physical habitat that they provide[28].

The initial calculations for the Dariali HPP environmental flows assume the 10% value. However, the method itself states that 10% of the average flow would support poor habitat conditions, and a 20- 30% of average flow or higher would be needed to support the optimum range for aquatic organisms (see **Table 10**).

The method has been criticised for its assumptions, primarily because its transferability from the US to other areas/environments is questionable, e.g. King *et al*. 2008[29] and Tharme, 2000[30]. It also seems that, in this case, the method has been applied considering the minimum flow to provide for short-term survival, rather than the flow to support acceptable or favourable conditions.

[28] Tennant, D.L. (1976) Instream flow regimens for fish, wildlife, recreation and related environmental sources. *Fisheries*, 1(4); 6-10
[29] King, J.M., Tharme, R.E. and de Villiers, M.S. (2008) Environmental flow assessments for rivers: Manual for the building block methodology (Updated Edition). *Water Research Commission Report No TT 35/08.*
[30] Tharme, R.E. (2000) International trends in the development and application of environmental flow methodologies: a review. *Water Research Commission Technology Transfer Report.*

Table 10 Tennant (Montana) method (1976) recommended flows as a percentage of the Mean Annual Flow (MAF).

Description of general condition of flow	Recommended flow regimens (% of MAF), October to March.	Recommended flow regimens (% of MAF), April to September
Flushing or Maximum	200	200
Optimum Range	60-100	60-100
Outstanding	40	60
Excellent	30	50
Good	20	40
Fair or Degrading	10	30
Poor	10	10
Severe degradation	<10	<10

8.2 European practice

A number of countries across Europe have defined a minimum maintenance flow in rivers affected by water storage in reservoirs[12]. These are summarised in **Table 11**[12] and expressed in terms of % of mean annual flow. These figures have been summarised in **Table 12**.

Table 11[12] European maintenance flows.

Country	Maintenance Flow Value	Maintenance Flow Value as proportion of annual mean flow
Austria	Must be: At least 20% of natural daily flow and, when flows are low, not less than: the lowest daily minimum flow at least one third of the natural mean annual minimum flow for water bodies where the lowest daily flow is less than a third of the mean annual minimum at least half of the natural mean annual minimum flow for water bodies with a mean flow below 1 m³/s.	20%
France	5 % to 10% of mean annual flow	5 to 10%
Norway	Q95.	6 to 12%
Romania	In general, Q95 (yearly minimum monthly mean discharge with 95% probability of occurrence) is recommended as "guaranteed" flow. In the first RBMP (River Basin Management Plans), based on the available studies done by the research institutes, EF was considered to be the minimum between Q95 (yearly minimum monthly mean discharge with 95% probability of occurrence) and 10% out of the mean discharge averaged on many years. The minimum release is approximately 10 % of mean annual flow or Q95.	10%
Slovenia	Minimum release varies from 8 % to 22 % of mean annual flow	8 to 22%
UK	75 - 85% of Q95.	6 to 19%

Table 12 Summary statistics of environmental flows around Europe

Statistic	**Environmental flow as a percentage of the mean annual flow.**
Maximum	22% (Slovenia)
Minimum	5% (France)
Upper range mean	13.3%
Lower range mean	7.9%
Upper and Lower range Mean	10.6%

Many of the above figures precede introduction of the Water Framework Directive (WFD), which is driving a major review of how environmental flows are derived by regulators.

8.3 Calculating environmental flows under the WFD

The UK Technical Advisory Group (UKTAG) is a leading movement in best practice in relation to the implementation of the requirements of the Water Framework Directive (WFD). UKTAG makes technical recommendations to the UK government administrations on implementing the Water Framework Directive ("the Directive"). It is a working group of experts drawn from the UK environment agencies and conservation agencies. It also includes representatives from the Republic of Ireland. UKTAG have recently published guidance on "River Flow for Good Ecological Potential"[12], in the context of impoundments that artificially alter the flow regime of rivers.

8.3.1 Building blocks methodology

The approach of the building blocks methodology (BBM), updated by UKTAG (2013)[12] for the UK for WFD requirements in impounded water bodies, may be appropriate in order to assess how understanding of current conditions can be used to define environmental flow requirements for the Tergi River at the Dariali HPP location. The methodology is based in a natural flow paradigm that assumes that the natural flow regime will provide the best possible conditions for ecosystem functioning, and identifies building blocks required to continue supporting that functioning (**Figure 16**).

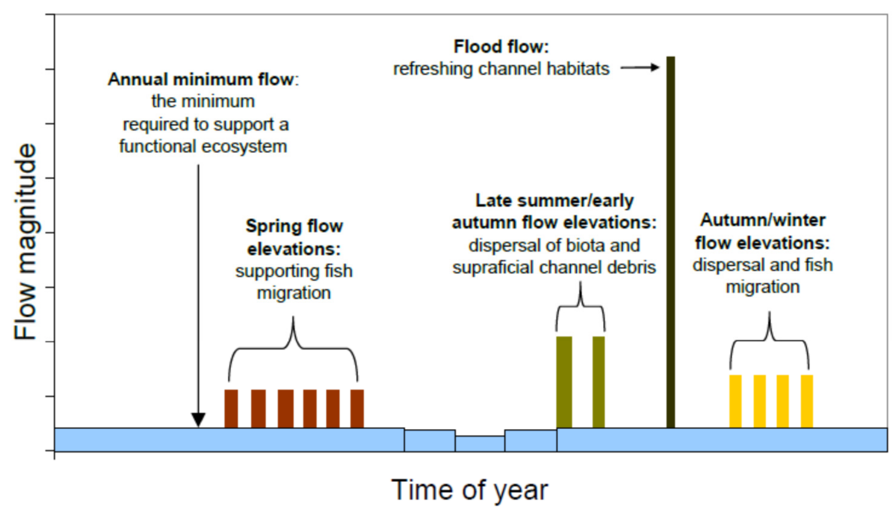

Figure 16 Schematic representation of a mitigation flow regime based on the recommended flow building blocks (from UKTAG, 2013[12]).

The flow regime required to support fish populations have five important characteristics:

- supporting a functioning ecosystem;
- supporting fish migration in the spring;
- dispersing biota and supraficial channel debris in late summer/early autumn;
- refreshing channel habitats;
- dispersal and fish migration in the autumn/winter months.

Acreman *et al.* (2009)[13] have proposed a ten step approach to define the required environmental flows for a water body (**Table 13**). Although the steps have been defined for the UK, a similar approach is transferable.

Table 13 Ten steps required to define an environmental flow release regime using the building blocks methodology (from Acreman *et al*., 2009[13])

Step	Activity
1	Define a natural flow regime for the water body in terms of daily discharge time series for a representative 10-year period
2	Analyse the flow regime in terms of the magnitude, frequency and duration of high, medium and low flows
3	Assemble biological survey data or use models for the water body to determine the expected biological communities and life stages for the river in reference condition
4	Determine flow regime requirements for each species/community and life stage using published literature
5	Verify the requirements by identifying elements of the flow regime in the historical record
6	Check that flow release elements will deliver other important variables such as water quality, including temperature and sediment load
7	Define the building blocks
8	Record results in an environmental flow release regime table
9	Add up individual flow needs to assess overall implications for water resources
10	Repeat the analysis for each water body ensuring that environmental flow upstream is sufficient to meet needs downstream

8.4 Application to the Tergi River at Dariali

To derive a scientifically robust recommendation for an environmental flow that will avoid negative impacts on the local trout population on the Tergi River requires a process similar to that outlined in **Table 13** to be followed. This process will need to be adapted to the local conditions. The embankment is to be constructed in 2014 (and begin operation in July 2015), and a design which can accommodate managed adaptations in its operation is critical.

A daily discharge time series has not been made available to Arup, the data that are available are not contemporary and flows ceased to be monitored after 1990. The available data provides an indication of the monthly average hydrological conditions (and 10-day average flows) in which current fish populations survive. Provided the presence of trout populations is verified, it can be inferred that these flows are currently sufficient to:

1. Support spring migrations into and within the system (assuming such migrations happen periodically, and not in a phased manner in response to food availability and other system conditions);

2. Support autumn migration and spawning (assuming such migrations happen periodically, and not in a phased manner in response to food availability and other system conditions);
3. Sustain populations of benthic fauna and flora at the base of the ecosystem, including through the winter months;
4. Refresh channel habitats and disperse biota and supraficial debris.

Current knowledge indicates that the only species present on the upper Tergi River is *Salmo trutta fario*. This, in principle, makes the process involved under Step 4 simpler, although comparatively little is known about how this species has adapted itself to suit the local environment. From what is known of this species, the issues and concerns associated with the proposed environmental flows are shown in **Table 14** below.

Table 14 Building block flows and risks

'Building block' flow required to…	**Issues**
Support spring migrations (April –June) into and within the system.	The onset of migration is affected by a number of factors , but increased temperature and river flow are of primary importance. Following implementation of the scheme flows will still increase rapidly in the Spring. A portion of the initial increase will be abstracted and the peak flows downstream will also be reduced. This impact will be further assessed through monitoring. (assuming such migrations happen periodically, and not in a phased manner in response to food availability and other system conditions).
Support autumn migration and spawning.	Flows will be unaffected in any spawning areas upstream of the proposed dam. In the reach downstream of the dam, the flows will be lower during the autumn months. Flows need to be sufficient to support this autumn migration and the adequacy of the proposed environmental flow should be assessed through monitoring. (assuming such migrations happen periodically, and not in a phased manner in response to food availability and other system conditions).
Sustain populations of benthic fauna and flora at the base of the ecosystem.	The proposed flow reductions resulting from the abstraction will reduce the extent of available aquatic habitats, particularly in braided reaches, between the dam and the tailrace. It is thought unlikely that fish use these areas as spawning grounds nor that fish feed in, or migrate through, these reaches during the winter months. However, this will be confirmed through monitoring and adjustment of mitigation measures where necessary.
Refresh channel habitats and disperse biota and supraficial debris.	The proposals will have little impact on the periodic flood flows responsible for these processes.

9 Environmental Mitigation

9.1 Environmental Flow

As stated in Section 8.4, there are significant risks that an environmental flow of 2.54m^3/s, in conjunction with the proposed abstraction regime, whereby all flows above this levels are abstracted unless the river flow exceeds 33 m^3/s, will negatively impact the river ecosystem. It is therefore recommended that the dam be constructed in a manner which will allow for its managed adaptation once the nature of these impacts is understood, and that active and appropriate adaptive management measures are undertaken during operation. This can be achieved by inclusion of a sluice gate directly adjacent to the fish pass that can be used specifically for the purpose of adjusting and regulating pass forward environmental flows. Details of the proposed monitoring and management recommended to inform the operation of this sluice are provided in Section 10.

9.2 Channel modifications

It is possible in some circumstances to mitigate the impacts of flow reductions by making physical modifications to the receiving watercourse. For example, channel size and form can be re-configured to provide good hydraulic conditions for fish should discharge be changed.

The geomorphological system on and around the River Tergi is very dynamic, and prone to catastrophic debris flow events and extreme floods, which are capable of moving very large boulders and volumes of sediment. It is for these reasons that large scale physical mitigation in the form of channel modifications designed to create a channel more suitable for the reduced flows is not recommended as it would be unsustainable long-term.

It is important that the effects of the proposed environmental flow in the autumn recession is observed the first time they occur in order to check for areas of non-continuous channel in the braided and steep boulder-bed sections. Should the channels become non-continuous then sediments could, in principle, be moved in order to create a continuous channel until a sustainable environmental flow solution is implemented through adaptive management.

9.2.1 Fish Passes

A facility for fish to move over the dam at the Dariali HPP site is to be provided by a pool and weir type fish pass at an overall gradient of about 12.5%. Head loss between pools is 0.2m which provides for a maximum velocity of 2m/s, compatible with the swim speed for the species present[31].

The conceptual type of fish pass design is appropriate for the salmonid species present in the river, provided key criteria relating to attraction flow, in-channel velocities and water depth are achieved. This type of fish pass is not suitable for benthic species such as barbell, but the ESIA[3] suggest that only trout are present. The presence of barbel and other species should be confirmed prior to the design

[31] Ref: EA Fish Pass Design Manual Table 4 (pg72) and DVWK Fish Passes para 3.4

being completed to permit the pass to be adapted if required. Such adaptation could be achieved with relative ease.

To be as effective as possible, the fish pass entrance should be located as close to the downstream side of the dam as possible and should provide a stronger attraction flow, when compared to competing sources (such as any flow emanating from the sluices), at the anticipated range of migration flows.

It is a requirement for this type of pass that sufficient volume is provided within the fish pass pools to effectively dissipate energy. The flow regime should be confirmed to ensure that energy is low enough for fish to ascend. Provision for fish to exit the head of the pass must allow for variations in water levels with any flow control measures designed to avoid high velocity areas which fish may be unable to overcome. In principle, this should be achievable with a flow of 2.54 m^3/s. However, insufficient detail is available to enable a confident assessment to be made regarding the hydraulic efficiency of the design as currently presented. It is recommended that the final design of the fish pass is checked at the earliest opportunity to ensure compliance with best practice guidelines. It is also important that attention is paid to details of features within the fish pass channel and that the structure, as built, complies with the design.

10 Monitoring and adaptive management regime

The importance of monitoring the environmental performance of schemes has been stressed by the EBRD, with appropriate procedures established and results used "to correct and improve operational performance"[2]. Ideally, a strong understanding of the **baseline conditions** of a system is required in order to be able to assess with confidence what changes are taking place in the studied system. The main **objectives** of the monitoring strategy would be as follows:

- To establish the baseline physical habitat and flow conditions;
- To establish the presence, migration, feeding and spawning habits of the local fish population;
- To identify the relevant building block flows required to sustaining the above;
- To develop a managed adaptive strategy to achieve these building block flows.
- To assess the impacts of the scheme as implemented and the effectiveness of the mitigation measures proposed.

In the case of the Dariali HPP project, some baseline data exists. This data, however, has not been collected in a systematic manner specifically to answer questions about the local fish population. In terms of flora and fauna, for instance, the objective of the surveys was to compare the scheme site to potential compensation sites. Thus, the surveys provide some valuable information, but are not readily useable for long-term monitoring purposes. Furthermore, some of the sampling techniques are non-standard and would not be replicable, which is a crucial aspect of a successful monitoring strategy. Information provided regarding fish is uncertain, and at times contradictory. More detail regarding the baseline habitat conditions is also required to understand the impact of any changes likely to be caused by the Dariali HPP scheme.

A well-defined and focused monitoring strategy is therefore required in order to obtain a robust understanding of the baseline conditions of the Dariali site. This baseline understanding will then permit evaluation of the ecological and geomorphological effects of the scheme. This will also provide a stronger basis for the assessment of the recommendations for the Dariali HPP scheme (section 5) and inform any required adaptive measures.

A multiple approach monitoring strategy is required in order to ensure that the objectives are achieved. Standard methodologies that can be replicated should be used, so baseline and post-construction conditions can be compared. Although some specific methods will need further definition and/or refining, **habitat monitoring, ecological monitoring** and **fish passage monitoring** in the areas affected by the proposals should be conducted. Baseline and post-construction monitoring of existing conditions at Dariali of at least the following will be necessary:

- Pre-commissioning monitoring of flow, fish and habitat conditions at, upstream and downstream of the proposed dam, to inform an initial mitigation strategy;

- Repeat monitoring of the above after commissioning of the HPP for at least 5 years. A review of monitoring at the 5 year period may reveal that additional monitoring is needed;
- Monitoring of the effectiveness of the fish pass;
- Assessment of monitoring results and evaluation of any residual adaptive management requirements.

10.1 Flow and Physical Habitat Monitoring

The monitoring should be defined by the key parameters of habitat condition that control the presence of fish and its associated food chain. The monitoring include:

- Continuous gauging of discharge, temperature and velocity;
- Geomorphological mapping (e.g. habitat reaches / flow types), lateral water and sediment inputs, relevant features etc (including in the immediate area downstream of the Dariali tailrace);
- Intermediate channel cross section data including dimensions, hydraulic roughness, depths and velocities;
- Extent and location of the river channel (and tributaries) that is subject to freezing.

10.2 Ecological Monitoring

A rigorous approach is required for ecological monitoring to ensure methods are standardised and repeatable. Appropriate locations should be chosen and geo-referenced after the habitat mapping has identified relevant fish habitat units within the system and at control sites outside the depleted reach between the headrace and the tailrace of the HPP scheme. The results of the monitoring should contribute to the description of the current status, detect changing trends and compare systems. The sampling should aim to assess community assemblages and target different life stages, using, for instance:

- Standard time invertebrate sampling (method dependent on water depths);
- Assessment of trout redds;
- Acoustic fish tagging (the timing and nature of which is to be advised on by the specialists designing and undertaking the detailed monitoring programme).

10.3 Fish pass monitoring

Besides ensuring that reduced flows do not negatively affect fish populations in the area, monitoring should also be conducted to assess the performances of the fish ladders installed at the Larsi and Dariali, to ensure that fish can indeed use them to overcome the artificial barrier. Specific methods and their application will need to be agreed, but at this stage, acoustic fish tagging, pit tagging or continuous monitoring with underwater cameras can be considered as options.

10.4 Monitoring approach

It is recommended that at least part the monitoring programme should be undertaken as PhD research focused on understanding fish populations, movements and life cycle activity within the study area (Dariali HPP depleted reach and control areas). Also, levels and scales of autotrophism and links to morphology will be considered, and causal relationships identified.

Further details should be agreed by the funding body and the educational institutions, but in principle, the research would be conducted by a Georgian PhD candidate who will have ambitions to live and work in the region after obtaining their PhD degree. The PhD student will be based at a Georgian institution, such as Ilia State University, and its Institute of Zoology, and supervised by an academic at that institution. Other options could be the Institute of Applied Ecology at Tbilisi State University. The student would be co-supervised by relevant professor at a University with a large and well established specialist fisheries research department so that appropriate training required for the monitoring could be undertaken. The monitoring programme will be designed with a local focus, whilst following internationally-transferable field and data analysis methodologies.

The first fish monitoring season could be supported by researches from other institutions / organisations and could be used to train a local team (potentially composed of other researches / PhD students at the local university) for years 2 to 4 of the PhD. Ilia State University has recently started a Master Programme on Natural Resources Use, which could be a valuable resource in terms of providing potential support for the monitoring field work, while offering opportunities for individual dissertations.

Flow data and geomorphological information will be provided by Dariali HPP and the geomorphological team respectively. Results from the monitoring will be kept in a life document that can inform adaptive management.

10.5 Public Engagement and Education

The scheme will provide a good opportunity for public engagement and education activities. Information from the scheme should be made available, together with key findings from the monitoring programme highlighting the value of the area. Panels in the area could be used for this purpose. This information could be used to reinforce public campaigns to emphasize the need to stop fly tipping in the area.

Additionally, the possibility of involving local schools in some of the monitoring activities should be investigated. This would serve a twofold purpose; it would encourage positive attitudes towards valuing and protecting the environment, whilst making a positive contribution towards the scheme. This contribution will require further definition, but could input, for example, into mapping the terrestrial fauna and flora of the system, or into observing changes to specific aspects of the system. The scheme also provided an opportunity to provide dissertation topics to higher education students that can add value to understanding of both the scheme itself and its environmental aspects.

Public engagement and education activities are discussed further in the Dariali HPP Environmental and Social Impact Assessment Report[3].

11 Conclusions and recommendations

Currently the scheme makes an allowance of 10% of the estimated average annual flow (as is standard practice in Georgia) at the intake, based on gauged records observed at a nearby gauging station from 1928 to 1940 and from 1953 to 1990. This equates to a flow of 2.54 m^3/s.

The United Kingdom Technical Advisory Group (UKTAG) has produced best practice guidance on deriving environmental flow requirements. The approach uses the 'building blocks' methodology assumes that the natural flow regime will provide the best possible conditions for ecosystem functioning, and identifies key flows (building blocks) required to continue supporting that functioning. The table below identifies the building block flows likely to be of relevance to *Salmo trutta fario* and the issues that the HPP proposals raise.

'Building block' flow required to…	**Issues**
Support spring migrations (April –June) into and within the system.	The onset of migration is affected by a number of factors , but increased temperature and river flow are of primary importance. Following implementation of the scheme flows will still increase rapidly in the Spring. A portion of the initial increase will be abstracted and the peak flows downstream will also be reduced. This impact will be further assessed through monitoring. (assuming such migrations happen periodically, and not in a phased manner in response to food availability and other system conditions).
Support autumn migration and spawning.	Flows will be unaffected in any spawning areas upstream of the proposed dam. In the reach downstream of the dam, the flows will be lower during the autumn months. Flows need to be sufficient to support this autumn migration and the adequacy of the proposed environmental flow should be assessed through monitoring. (assuming such migrations happen periodically, and not in a phased manner in response to food availability and other system conditions).
Sustain populations of benthic fauna and flora at the base of the ecosystem.	The proposed flow reductions resulting from the abstraction will reduce the extent of available aquatic habitats, particularly in braided reaches, between the dam and the tailrace. It is thought unlikely that fish use these areas as spawning grounds nor that fish feed in, or migrate through, these reaches during the winter months. However, this will be confirmed through monitoring and adjustment of mitigation measures where necessary.
Refresh channel habitats and disperse biota and supraficial debris.	The proposals will have little impact on the periodic flood flows responsible for these processes.

The environmental flow of 2.54 m^3/s is likely to be sufficient to allow fish to travel up the proposed fish pass, provided it is designed in accordance with best practice. This figure is also consistent with the environmental flow that would be legally required for the same river in other countries, including EU countries with alpine river basins. This environmental flow value is therefore considered as a reasonable initial value to develop the Project until the further site specific data is available.

There is currently insufficient scientific information available on the river ecology and particularly on the specific environmental flow requirements of *Salmo trutta fario*. In addition, the Tergi river environment is changing under the influence of two recent run-of-river hydropower schemes immediately downstream from the proposed Dariali HPP: Larsi HPP, Georgia, under completion and Ezminskaia HPP Russia (completed). It has therefore been decided to adopt the precautionary approach through a monitoring driven adaptive management plan. Adaptive management will allow, for example, temporary adjustments in the environmental flow to support seasonal migrations around April and October, if such migrations were confirmed by the fish monitoring program. It is therefore recommended that:

- A monitoring programme is developed to confirm that the proposed minimum environmental flow is sufficient to support the above requirements;
- The design be reviewed to ensure that the sluice directly adjacent to the fish pass can, if necessary, be adjusted to pass forward environmental flows in the river in a manner that ensures fish are attracted to the fish pass;
- Geomorphological monitoring (focused on immediate channel continuity, fine sediment flushes, geomorphological response to the altered regime and extent of freezing) is undertaken to inform adaptive management and ecological monitoring;
- At least one season of monitoring occurs prior to the scheme being commissioned and continues for at least three years after commissioning (this could be associated with PhD research);
- A management regime is established based on operational experience that takes the results of the monitoring directly into account;
- The above is used to inform a public engagement, education and awareness-raising strategy.

The pre-construction monitoring may demonstrate that fish are present in the affected reach during the winter months, or that spawning occurs in this reach. In this case, adaptation of the current proposals is likely to be required in order to support:

- Spawning in the impacted reach before winter in areas that are susceptible to drying out and / or freezing;
- Residence in the impacted reach during winter.

Alternatively the monitoring may demonstrate that fish do not spawn here, nor are they resident here in the winter. It is also possible that, if significant fish migration activity is shown to occur in certain periods, that increased flows (above the 10% environmental flow) may be needed at these times.

[i] Independent Specialist to Provide Expert Advice on Aquatic Biodiversity Conservation, Dariali Hydropower Project, Georgia, ToR.