Nenskra Hydropower Project

Supplementary Environmental & Social Studies

Volume 6
Natural Hazards & Dam Safety

Supplementary E&S Studies for the Nenskra HPP:

Volume 1 Non-Technical Summary	Volume 2 Project Definition	Volume 3 Social Impact Assessment	Volume 4 Biodiversity Impact Assessment	Volume 5 Hydrology & Water quality Impact assessment
Volume 6 **Natural Hazards and Dam Safety**	Volume 7 Stakeholder Engagement Plan	Volume 8 Environmental & Social Management Plan	Volume 9 Land Acquisition & Livelihood Restoration plan	Volume 10 Cumulative Impact Assessment

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Acronyms

ADB	Asian Development Bank
AIIB	Asian Infrastructure Investment Bank
ANCOLD	Australian National Committee on Large Dams
asl	above sea level
CTGREF	*Centre technique du Génie Rural des Eaux de des Forêts* (Technical Center for Rural Engineering, Water and Forests)
DinSAR	Satellite Radar Interferometry
DTM	Digital Terrain Model
E&S	Environmental and Social
EAP	Emergency Action Plan
EBRD	European Bank for Reconstruction and Development
EIB	European Investment Bank
EPC	Engineering Procurement Construction
ESIA	Environmental and Social Impact Assessment
GLOF	Glacial Lake Outburst Flood
GMPE	Ground Motion Prediction Equation
Ha	Hectares
ICOLD	International Commission on Large Dams
IPoE	Independent Panel of Experts on Dam Safety
kV	Kilovolt
m	Metres
m/s	Metres per second
m^3/s	Cubic metres per second
MCE	Maximum Credible Earthquake
MCT	Main Caucasus Thrust
MMS	Moment Magnitude Scale (= Mw)
MSK	Mededev-Sponheuer-Karnik scale
MW	Megawatt
OBE	Operating Basis Earthquake
OFEN	*Office Fédéral de l'Energie* (Swiss Federal Office of Energy)
PGA	Peak Ground Accelerations
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RTS	Reservoir Triggered Seismicity
SCS	Soil Conservation Service
T (h)	Time in hours
WCSZ	West Caucasian Source Zone

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Preamble

The Nenskra Project is developed by JSC Nenskra Hydro (also called the Project Company in this document), whose main shareholders are K-water - a Korean government agency - and Partnership Fund, an investment fund owned by the Government of Georgia.

In August 2015, the final Environmental & Social Impact Assessment Report (ESIA) for the proposed project was submitted to the Government of Georgia as part of the national environmental permitting process. The 2015 ESIA report had been prepared by Gamma Consulting Limited (Gamma) – a Georgian environmental consulting company. The ESIA was based on the findings of field investigations undertaken in 2011 and 2014. Public consultations meetings were held in May 2015 and the Environmental Permit was awarded by the Environmental Authorities in October 2015. In the present document, the ESIA submitted in 2015 is referred to as the 2015 ESIA.

Since then, several International Financial Institutions (the Lenders) have been approached to provide financial support to the Project. To ensure compliance with their environmental and social policies, the Lenders have recommended that a number of supplementary Environmental and Social (E&S) studies be undertaken to supplement the 2015 ESIA.

This report is the final version of Volume 6 of the supplementary E&S studies, prepared on behalf of the Project Company by SLR Consulting and issued after the public disclosure period held from March-September 2017 and takes into account the comments received from the various stakeholders engaged with by the Project. The document compiles information from different natural hazard and dam safety studies prepared by the Project. This document provides readers with the current knowledge regarding natural hazards in the Project area and the safety of the dam. The purpose is to demonstrate how the Project has identified and addresses hazards to ensure the safety of workers and communities.

It must be read in conjunction with the other volumes of the supplementary E&S studies organised as follows:

- Volume 1: Non-Technical Summary
- Volume 2: Project Definition
- Volume 3: Social Impact Assessment
- Volume 4: Biodiversity Impact Assessment
- Volume 5: Hydrology and Water Quality Impact Assessment
- **Volume 6: Natural Hazards & Dam Safety** (**this volume**)
- Volume 7: Stakeholder Engagement Plan
- Volume 8: Environmental & Social Management Plan
- Volume 9: Land Acquisition & Livelihood Restoration Plan
- Volume 10: Cumulative Impact Assessment

Summary

A. Introduction

This document is the natural hazards and dam safety study prepared as part of the supplementary E&S studies for the Project. The purpose of this document is to provide readers with information regarding natural hazards in the Project area and how these are accounted for to ensure the safety of the Project and of people working on it – during construction or operation – or living downstream from it. The Project has undertaken numerous studies in relation to natural hazards and dam safety, and the key studies used in the preparation of this report include hydrological studies, earthquake hazard assessment, natural hazards risk assessment, and slope stability studies.

B. Risk management overview

The Project's overarching objective in terms of risk management is that workers and communities are not exposed to risks that exceed tolerable limits as defined by Good International Practice. To meet this end, the risk management process adopted by the Project follows the framework developed by the Swiss system of natural hazard risk assessment and comprises a complete framework for risk assessment of natural hazards developed by the World Meteorological Organisation. The Project natural hazard risk assessment has been carried out following the approach recommended by the International Commission on Large Dams (ICOLD). In addition, the hazard studies have gone through a thorough review process. The studies performed by the EPC Contractor have been reviewed by the Owner's Engineer (OE), the Lender's Technical Advisor (LTA) and an Independent Panel of Experts on Dam Safety (IPoE). The IPoE comprises experts in the field of geology & seismology, tunnelling, floods and natural hazards, dam structural and operational safety, public safety and social and community issues. The overarching objective of the IPoE is to review the Project with respect to compliance with Good International Practice relating to all matters of dam safety and the safe design and construction and efficient operation and maintenance of the project components. During the review process a number of design changes have been made in order to best mitigate risk. These are described in the main report in section 2.

C. Natural hazard risks in the Nenskra valley

C.1 Risks to assets and personnel

The Project's natural hazards assessment has identified and evaluated the potential for natural hazard events to affect the assets and Project personnel. The key findings are as follows:

Extreme flood events	Hydrological studies[1] have been undertaken to characterise hydrology and establish the Probable Maximum Flood (PMF), which is 1,145 m^3/s. The dam is equipped with a spillway with a capacity to evacuate the PMF. In addition, the bottom outlet is designed to evacuate 200 m^3/s (equivalent to the 100-year flood). In the case of a bottom outlet gate malfunction, the discharge could reach 317 m^3/s. A Climate Change Risk Assessment has been commissioned by JSCNH and is currently ongoing. If the assessment finds that climate change increases the PMF, the Project will revise the spillway design and construct a spillway that can accommodate the revised PMF if necessary.

[1] Data used was from 7 river gauging stations and spanning the period 1937 to 2004. No gauging station covers the complete period.

Seismicity	An earthquake hazard assessment has been carried out and the Maximum Credible Earthquake (MCE) has been determined - which is 7.5 on the Moment Magnitude Scale (equivalent to approximately 7.2 on the Richter scale). The corresponding Peak Ground Acceleration (PGA) at the dam site has been determined and is 0.65 g (at top of alluvium). Physical and numerical modelling of the dam stability and capability to withstand the PGA has been undertaken, and has confirmed that the dam will resist an MCE event without failing.
Reservoir Triggered Seismicity (RTS)	The creation of a large dam-reservoir can result in a detectable change in the frequency of seismic events. In view of this and the recommendations of ICOLD, the possibility of RTS has been studied by the Project as part of the Project's Earthquake Hazard Analysis. The study has concluded that RTS of a magnitude of less than 4.5 on the Moment Magnitude Scale (equivalent to approximately 4.5 on the Richter Scale) could occur. Seismicity of this magnitude can be felt by people, but does not cause damage to buildings, without the dam, 35 events of this magnitude occur per century, i.e. one event every two to three years. RTS is most likely during the reservoir filling and consequently reservoir filling will be undertaken at a rate lower than 12 metres water depth increase per week. Seismic activity will be monitored during reservoir filling, and filling rate slowed or stopped if an increase in seismicity is detected. During operation, seismic activity will continue to be monitored.
Glacial Lakes	The Project's natural hazards assessment included a helicopter flyover to identify glacial lakes in the upstream catchment and has concluded that there are two glacial lakes in the catchment area. However, the lakes are not of a size that the volume of water released in case of a Glacial Lake Outburst Flood (GLOF[2]) would represent a risk to the dam structure. In addition, the physical presence of the dam-reservoir would protect the downstream population from such an event. Nevertheless, in the highly unlikely event of a GLOF, the inflow into the reservoir could transport solid material that could block the dam's bottom outlet, or spillway which are safety features. See spillway and bottom outlet below.
Nakra transfer tunnel outlet portal	The structure has been positioned away from avalanche and rockfall hazards. However, there is a moderate risk of rockfall. Consequently, rockfall protection measures will be included in the design and built to protect the structure, worksites and workers.

[2] A Glacial Lake Outburst Flood (GLOF) is a flood occurring when water dammed by a glacier or a moraine is released as a result of the failure of damming material

Nenskra dam and reservoir	The dam is situated on the alluvium deposits from a past landslide. However, the natural hazard risk assessment including a slope stability assessment using satellite radar interferometry has concluded that there is a low risk of further instability in the zone. The dam is positioned in a zone exposed to avalanche and debris flow[3] and the risks are estimated as moderate for the structure and for personnel. Protection measures will be included in the design and will be built to protect the structure and personnel during construction and operation. Avalanche risk and slope stability will be monitored and in the unlikely event that a dangerous situation is detected the reservoir water level will be lowered by opening the bottom outlet and personnel moved to safe locations. The stability of slopes above the future reservoir have been assessed including the use of satellite radar interferometry. An area of potential instability has been identified 2.5 kilometres upstream from the dam – in the right (western) side of the valley. However, the overall conclusion of the assessment is that there is no evidence to suggest the possibility of general, larger-scaled slope instability. The largest volume of material that could credibly become detached and fall into the reservoir has a volume of 10,000 cubic metres – which is significantly smaller than the 176 million cubic metres of water contained in the reservoir – and calculations have shown that a resulting impulse wave from such an event would not overtop the dam.
Reservoir spillway	The spillway is exposed to moderate avalanche and debris flow risks and consequently protective measures will be included in the design to prevent blockage of the spillway – which is a safety feature – and also to protect the workers and the worksite during construction. The spillway is also vulnerable to floating debris that could block the spillway. The spillway is therefore designed with features to protect it from floating debris that could be brought into the reservoir by normal inflow, flood events – or in the very unlikely event of a GLOF.
Dam bottom outlet	Debris flow risk is moderate and consequently protective measures will be included in the design to prevent blockage of the bottom outlet as it is a safety feature and also to protect the workers and the worksite during construction. The bottom outlet will be cleared of any resulting blockages in the unlikely event of debris flow or very unlikely event that a GLOF occurs (see above) and which could block the outlet.
Headrace tunnel portal	Avalanche and debris flow risks are low and consequently protective measures will not be needed.
Surge shaft and penstock	Avalanche, debris flow and slope stability risks are low. However, there is a possibility of localised rockfall hazards, consequently rockfall protection measures will be included in the design and built to protect the structure, worksites and workers to reduce the risk to an acceptable level.

[3] Debris flow refers to a phenomenon in which water-laden masses of soil and fragmented rock descend mountainsides at great velocity, funnel into stream channels (often with additional erosion), carrying boulders and trees in their paths, and forming thick deposits on valley flanks and floor. The accumulation of successive debris flows leads to the formation of large fans or more precisely, in the context of steep slopes, debris cones – also known as alluvial fans.

Powerhouse	The powerhouse has been moved away from the nearby torrent in order to avoid debris flow and avalanche risk. However, the low debris flow risk will be confirmed through additional studies and if necessary protection measures included in the design to protect the powerhouse, the construction site and the construction workers.
Construction camps and technical installation	A preliminary assessment of natural hazards and temporary construction camps and technical installations has been carried out and has concluded that there are potentially moderate risks with regard to events such as avalanche, debris flow, rockfall etc. Further studies will be undertaken to design the protection measures necessary.

C.2 Risks to communities

The presence of the dam-reservoir has a positive impact in terms of reducing natural flood events. In the event of a flood, the reservoir will in many cases be able to contain some - or all - of the flood waters before the reservoir water level reaches the full supply level and spillage occurs. The reservoir also has a buffering effect and will reduce the floods peak flow. This reduction and buffering will be most noticeable for the more frequent and smaller flood events. Negative aspects are related to the risk of high unexpected flows downstream from the dam resulting from rare naturally occurring hazardous events, malfunction of control systems, and human error. The study describes the safeguards with respect to reducing the likelihood of the accidental situations.

An evaluation of the potential vibrations induced by the excavation of the Project tunnels has been carried out in view of establishing if there is a risk that tunnelling could trigger slope instability causing landslide that could affect communities, and if the vibrations could disturb communities. The findings of the assessment are that predicted vibrations at ground level are much lower than vibrations that could generate slope stability problems or disturb communities.

D. Natural hazard risks in the Nakra valley

D.1 Risks to assets and personnel

The Project's natural hazards assessment has identified and evaluated the potential for natural hazard events to affect the assets and Project personnel. The key findings are as follows:

- Extreme flood events, hydrological studies have been undertaken and the Nakra weir is a concrete structure designed to allow the safe overflow of the PMF which is 470 m^3/s.
- Nakra weir and transfer tunnel inlet portal: During the basic design, the position of the weir and tunnel inlet were moved further upstream to an area that is not exposed to potential avalanche and rockfalls.
- The preliminary natural hazard assessment for camps and technical installation has concluded that the Nakra camp and technical installations are potentially exposed to moderate avalanche/debris flow and rockfall hazards. Consequently, further studies will be undertaken as the Project progresses to best characterise the risks and to design protective measures for workers and facilities - including the accommodation camp.

D.2 Risk to communities

The study describes the increased risk of flooding in the Nakra valley that is an indirect result of the Project. The Nakra River is vulnerable to a risk of flooding as a result of mudflow events occurring on lateral tributaries. The mudflow events lead to temporary blocking of the Nakra River, creating temporary flooding upstream of the blockage, and downstream flooding when the river breaches the blockage. Without mitigation measures, the Project could result in an increase in this risk because the capacity of the river to flush away sediment will be reduced and there will be a tendency for sediment to accumulate in the river. To address this risk the Project will periodically open gates on the weir and close a gate on the Nakra transfer tunnel in order to reinstate the natural flow of the Nakra River. A study will be undertaken to establish the best solution for managing the existing sediment accumulation in the Nakra and to ensure that the exposure to floods is finally reduced and not increased.

An evaluation of the potential vibrations induced by the excavation of the Project tunnels has been carried out (see Nenskra valley above) and predicts vibrations will not cause slope stability problems or disturb communities.

E. Emergency planning

The development of an Emergency Preparedness Plan (EPP) is a regulatory requirement under Georgian law, is a requirement of Good International Practice and is a requirement of Lenders' E&S policies. The EPP needs to consider the very unlikely event of the dam failure, the mechanism (or failure modes) of dam failure, and flood studies to establish the areas at risk of flood.

E.1 Dam failure modes

The study presents the failure modes linked to natural hazards that could result in dam failure. The highly unlikely chain of events that could lead to a dam rupture are described and safeguards identified. The failure modes presented are as follows:

- Overtopping of the dam caused by: (i) an extreme flood event of a magnitude greater than that of the spillway capacity; (ii) blockage of the spillway when a flood event occurs; (iii) blockage of the spillway and the bottom outlet when a flood event occurs, and (iv) generation of a large impulse wave in the reservoir.
- Degraded dam stability caused by: (ii) rupture/damage of the asphaltic protective face of the dam causing internal erosion; (ii) external erosion from debris flow or avalanche; (iii) foundation erosion, and (iv) seismic event.

E.2 Consequences of dam failure

The report includes the results of a simple dam break model that has been used to establish how the rupture of the Nenskra dam would affect the Enguri dam-reservoirs situated downstream. In the very unlikely event of a failure of the Nenskra dam, a flood wave of 20 metres in height and a flow rate of 179,000 m^3/s would reach the Nenskra powerhouse area and then flow into the Enguri reservoir. The flood wave could cause overflow of the Enguri dam (assuming that the reservoir is at maximum operating level) and the depth of water of the overflow at the dam crest can be expected to be in the order of 12 metres.

E.3 Emergency preparedness plan

The Preliminary Emergency Preparedness Plan (EPP) is provided as an annex to Vol. 8 ESMP. The EPP will be developed into a final plan in H1 2018 – including the findings of flood modelling and will be available in H1 2018. The plan details the Project's responses to emergency conditions: (i) a dam failure; (ii) a downstream release; or (iii) situation potentially escalating to a dam failure or downstream release. The final plan will include a detailed dam failure analysis, dam failure hydrograph, routing of dam break flows, and inundation maps. The plan will also include details of response actions, early warning systems, communication systems, responsibilities, notification flowcharts, contact information, details of testing and exercises, evacuation and shelter-in-place training materials for potentially affected people and details of the annual public awareness campaigns.

1 Introduction

1.1 Background

1.1.1 Generalities

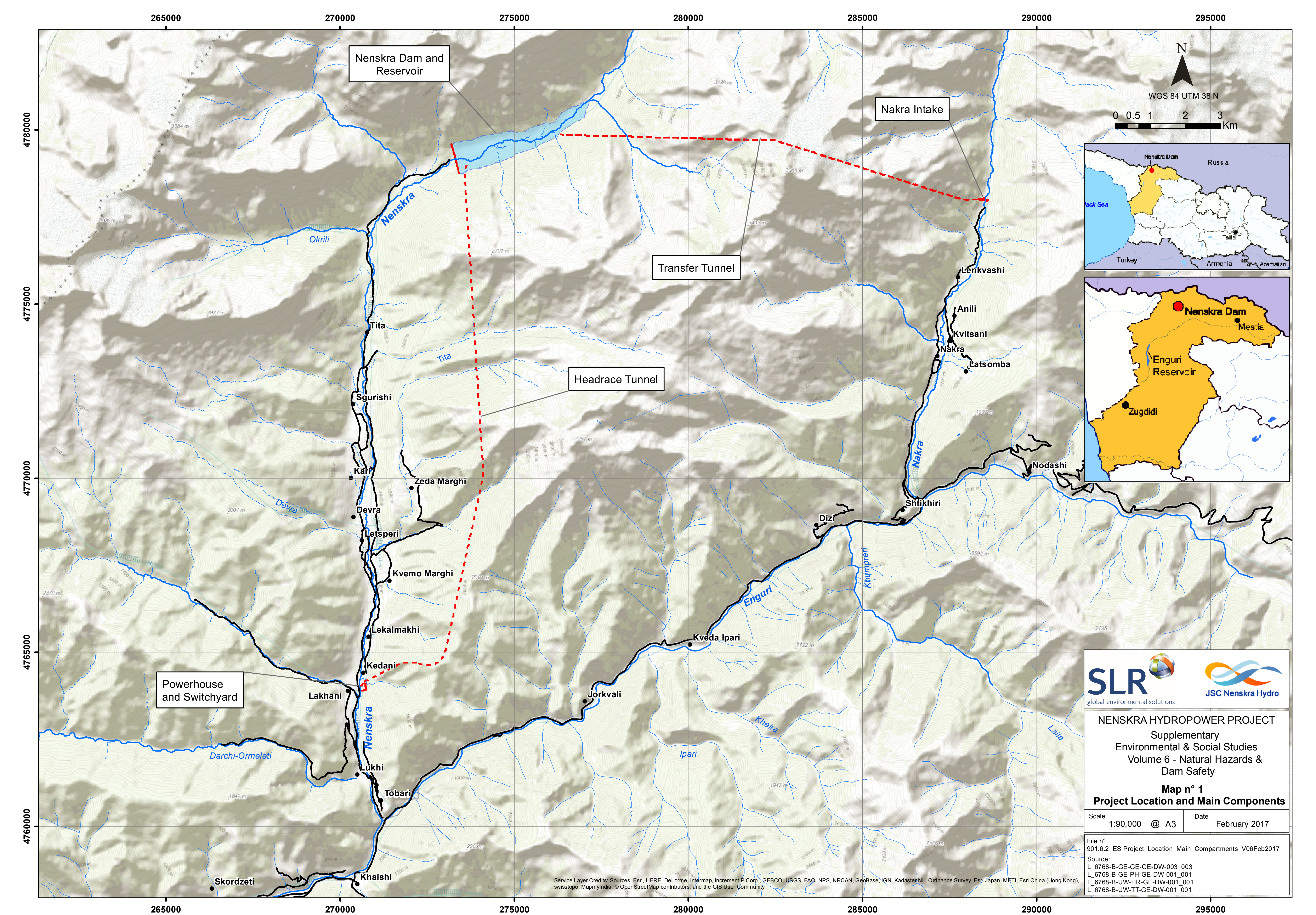
This document is the Natural Hazards & Dam Safety report prepared as part of the Supplementary E&S studies for the Nenskra HPP Project (the Project). Given the location of the Project in a mountainous region, one of the themes included in the supplementary E&S studies required is that of natural hazards and dam safety. The overarching objective of the document is to provide readers with information on natural hazards in the area and the how these are taken into consideration in the safety of the dam. The purpose is to demonstrate how the Project has identified and addresses hazards to ensure the safety of workers and communities. The Project has undertaken numerous studies in relation to natural hazards and dam safety, and by nature the documents are highly technical. This report has endeavoured to present the information in a less technical manner.

1.1.2 Project overview

The proposed Nenskra Hydropower Project is a greenfield high head hydropower project with an installed capacity of 280 MW, located in the upper reaches of the Nenskra and Nakra valleys in the North Western part of Georgia in the Samegrelo-Zemo Svaneti Region (see Map 1-1). The Project uses the available discharges from the Nenskra River and the adjacent Nakra River, developing a maximum available head of 725 metres down to the powerhouse located approx. 17 kilometres downstream the dam.

The main project components comprise a 125[4] metre high, 870 metres long asphalt face rock fill dam on the upper Nenskra River creating a live storage of about 176 million cubic metres and a reservoir area at full supply level of 270 hectares. The Nakra River will be diverted into the Nenskra reservoir through a 14.4-kilometre long transfer tunnel. The power waterway comprises a headrace tunnel of 15 kilometres, a pressure shaft and underground penstock of 1,580 metres long. The above-ground powerhouse is located on the left side of the Nenskra River and will house three vertical Pelton turbines of 93 megawatt (MW) capacity each, for a total installed capacity of 280 MW. A 220 kV transmission line between 1-5 kilometres long will connect the Nenskra powerhouse to a new substation in the lower Nenskra valley. The transmission line and the substation will be designed, built and operated by Georgian State Electrosystem. The main construction period is planned to start in Q1/Q2 2018 and will last 4 years. Some early works were started in October 2015 and are ongoing: upgrading of access roads and geotechnical studies. Power generation is planned to start in 2021 if the conditions are favourable. The Project is being developed by JSC Nenskra Hydro, whose main shareholders are K-water, a Korean government agency and Partnership Fund, an investment fund owned by the Government of Georgia. K-water and Partnership Fund are referred to as the Owners in this document.

[4] Dam height was previously disclosed as 130 m. Dam height is now referred to as 125 m as this relates to the height from the deepest point on the upstream face of the dam, whereas the 130 m previously quoted relates to the height from the deepest point on the downstream face of the dam. The reservoir full supply level and the design of the dam have not changed. This has been amended to provide consistency with other Project documents.



Nenskra Dam and Reservoir
Nakra Intake
Transfer Tunnel
Headrace Tunnel
Powerhouse and Switchyard
Nenskra
Nakra
Enguri
Okrili
Tita
Devra
Darchi-Ormeleti
Khumpreri
Kheira
Ipari
Laila
Lenkvashi
Anili
Kvitsani
Nakra
Latsomba
Nodashi
Shtikhiri
Dizi
Kveda Ipari
Jorkvali
Sgurishi
Kari
Zeda Marghi
Devra
Letsperi
Kvemo Marghi
Lekalmakhi
Kedani
Lakhani
Lukhi
Tobari
Khaishi
Skordzeti
265000
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275000
280000
285000
290000
295000
4780000
4775000
4770000
4765000
4760000
N
WGS 84 UTM 38 N
0 0.5 1 2 3 Km
Nenskra Dam
Russia
Black Sea
Tbilisi
Turkey
Armenia
Azerbaijan
Nenskra Dam
Mestia
Enguri Reservoir
Zugdidi
SLR
global environmental solutions
JSC Nenskra Hydro
NENSKRA HYDROPOWER PROJECT
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Map n° 1
Project Location and Main Components
Scale 1:90,000 @ A3
Date February 2017
File n°
901.6.2_ES Project_Location_Main_Compartments_V06Feb2017
Source:
L_6768-B-GE-GE-GE-DW-003_003
L_6768-B-GE-PH-GE-DW-001_001
L_6768-B-UW-HR-GE-DW-001_001
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1.1.3 Social and environmental context

The proposed location of the dam-reservoir is an isolated mountainous valley at an altitude of 1,300 metres above sea level, with the maximum operating water level at 1,430 metres. There are no villages or households living in the future reservoir inundated area or upstream of the inundated area. The only means of access to the dam is from downstream, following the Nenskra River and which is upgraded by the Project.

In the reservoir area, there are three summer cabins. Two are located immediately north of the future dam, and the third one is located at the end of the reservoir. These summer cabins are currently used in the summer months by local people who move their cattle to this area in the summer and also carry out artisanal logging, fishing or hunting activities.

Immediately downstream of the future dam is another group of ten summer cabins owned by the local communities and a forest guard's camp. This area will be occupied by the dam construction camp and technical installations during construction.

Five kilometres downstream from the dam is the hamlet of Tita, comprising one hotel and inhabited by 2 households. More densely populated areas (with a population in the order of 1,150 people - See Table 1 below) are located at a distance starting from 7 kilometres downstream from the dam and extending further downstream to the confluence with the Enguri, where the village of Khaishi is located.

Table 1 - Number of permanent inhabitants downstream from the dam

Community	Total Population	Estimated distance from dam
Nenskra Right Bank		
Sgurishi	154	~ 7 to 9 km
Kari	177	~9 to 10 km
Devra	52	~10 to 11km
Letsperi	100	~11 to 14km
Lakhami	233	~ 15 to 17 km
Lukhi	37	~ 17 to 19 km
Nenskra Left Bank		
Tita [*]	9	~ 5 to 6 km
Zemo Marghi	67	~9 to 11 km (up the slope, not near the river)
LariLari	100	~ 10 to 12 km
Kvemo Marghi	67	~ 12 to 15 km
Lekalmakhe	31	~15 to 16 km
Kedani	15	~ 16 km (to be resettled)
Tobari	22	~19 km
Total Nenskra Valley	***1,148***	

[*] The operator's village is also located downstream near the village of Tita and will accommodate between 50 and 60 people (10 family houses and 16 bachelor flats)

Source: JSC Nenskra Hydro - Socioeconomic survey, Sept-Nov. 2015

The Enguri dam reservoir is situated downstream from the Nenskra reservoir on the Enguri River, and there is project for the Khudoni hydropower scheme at the confluence of the Nenskra and Enguri Rivers. The upper reaches of the Khudoni reservoir will be immediately downstream of the Nenskra power house.

1.2 Scope of the study

The overarching objective of the document is to provide readers with the information regarding natural hazards in the area, how these are linked with dam safety, and how the Project has taken the hazards into account. The study therefore compasses the following main tasks:

- Synthesis of the specialist studies undertaken by the Project with respect to naturally occurring hazardous events which comprise extreme floods, seismicity, Reservoir Triggered Seismicity (RTS), avalanche, debris flow, slope instability, and glacial lake hazards.
- Describe dam failure modes with the links to natural hazard initiating events and description of the safeguards to mitigate the risks.
- Estimation of the consequences of the failure of the Nenskra dam using empirical calculations, including the effects on the downstream Enguri dam-reservoir.
- Presentation of the normal operation situations and accident scenarios that would result in a rapid increase in the flow of the Nenskra River downstream from the dam and which represent a risk to the safety of the local communities.
- Presentation of the flood risks associated with the hydrological and geomorphological changes in the Nakra River as a result of the Project.
- Description of the risks management measures that apply to the Project, in order to ensure that the Project meets Good International Practice.

1.3 Approach

The approach used in preparing the report is described as follows:

- Review and synthesis of project documents to identify main dam components, characteristics, implantation, and understand the operational modes of the hydropower scheme.
- Review and synthesis of specialist studies prepared by the Project related to natural hazards, seismicity, hydrology and slope stability.
- Preparation of the report.

1.4 Interactions with the other E&S Supplementary Studies

The interactions with other E&S supplementary studies are as follows:

- The Hydrology and Water Quality Impact Assessment report (Volume 5 of the Supplementary E&S studies) addresses identifies and characterises risks associated with geomorphological changes in the Nenskra and Nakra rivers. These aspects are integrated into this report as they concern community safety.
- The findings of this report are taken forward to the social impact assessment (Volume 3 of the Supplementary E&S studies).

1.5 Structure of this report

The report is structured into 6 main sections as follows:

- **Section 1 – Introduction**, provides a Project overview, background, context and scope.
- **Section 2 – Risk management framework,** provides a description of the approach used for managing risks, the review process and a summary of the changes in design that have taken place during the review process.
- **Section 3 – Natural hazard risk in the Nenskra valley,** provides the findings of the Project's natural hazard risk assessment with regard to the risk to assets and personnel. The section is structured by project component, and includes the findings of the hydrological studies, seismic hazard assessments and slope stability studies. The section also includes a description of the risks to communities as a result of the project and which comprise the exposure to sudden unexpected change in river flow rates triggered by natural hazards, malfunctions and human error.
- **Section 4 – Natural hazard risk in the Nakra valley,** adopts the same approach as for section 3 - though describing the situation for the Nakra. The section includes the a description of the risks to communities of flooding as a result of the projects reduced flow rate in the Nakra which reduce the capacity of the river to flush away sediment from mudflow events in the Nakra's tributaries.
- **Section 5 – Emergency planning,** describes the very unlikely sequence of events that could be triggered by natural hazard events and lead to dam failure modes. Safeguards to prevent such an event occurring are described, the preliminary estimation of the consequences of a dam failure are described and the information included in the Emergency Preparedness Plan is listed.
- **Section 6 - Synthesis of safeguards** provides a synthesis of the natural hazard and dam safety issues that are discussed in the report and the corresponding safeguard measures.

2 Risk management framework

2.1 Objective

The Project's overarching objective in terms of risk management is that assets, workers and communities are not exposed to risks that exceed tolerable limits as defined by Good International Practice.

The Project has the object to assess and mitigate the risks to assets, workers employed by the project – both for construction and operation - and people living downstream from Project structures.

This document has therefore endeavoured to differentiate where possible hazards, risks and safeguards for assets, Project personnel and communities.

The cases where natural hazard events can potentially affect structures causing a knock-on effect which would impact workers and/or communities – such as the case of dam failure - are evidenced.

2.2 Risk management process

The risk management follows the framework developed by the Swiss system of natural hazard risk assessment (SDC/PLANAT, 2005). and comprises a complete framework for risk assessment of natural hazards (World Meteorological Organisation, 1999) including schemes for hazard and risk assessment, definition of protection goals and planning of protective measures (*Kantonale Gebäudeversicherungen*, 2005 & 2007) as illustrated in the schematic below.

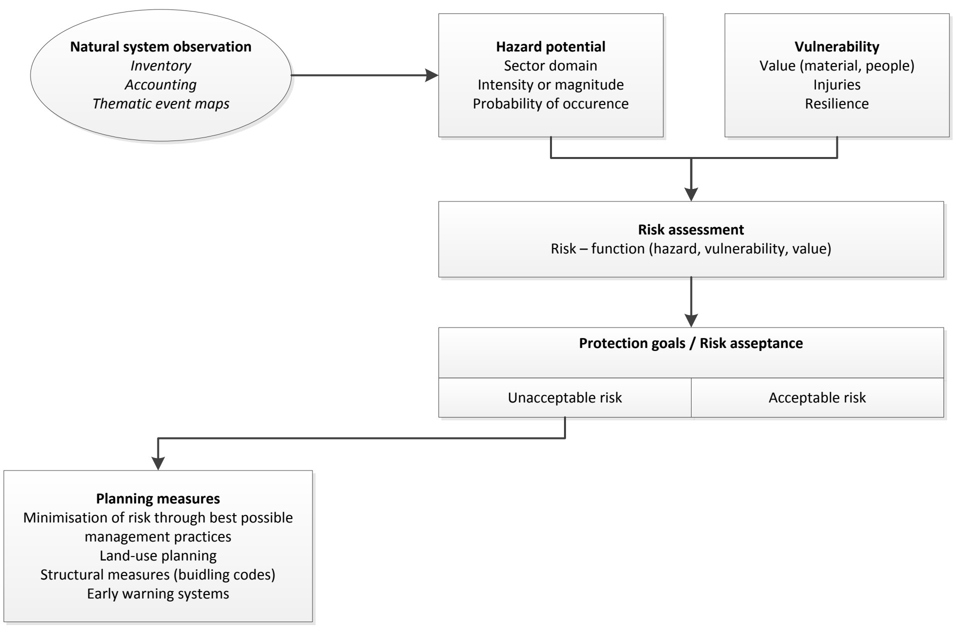


Figure 1 – Framework for risk assessment and risk management

A synthesis of the risk management programme is provided in Annex 6.

2.3 Review process

The hazard studies are subject to a review process. The studies undertaken by engineers engaged by the Project Company are reviewed by the Owners Engineer, and by the Lenders Technical Advisor. In addition, an Independent Panel of Experts on Dam Safety (IPoE) has been engaged to review all the Projects technical documentation. However, the final conclusions are owned by JSC Nenskra Hydro – the Project Owner.

The IPoE comprises experts in the field of geology & seismology, tunnelling, floods and natural hazards, dam structural and operational safety, public safety and social and community issues. The overarching objective of the IPoE is to review the Project with respect to compliance with Good International Practice relating to all matters of dam safety and the safe design and construction and efficient operation and maintenance of the project components. During the review process a number of design changes have been made in order to best mitigate risk. These are described in the main report in section 2.4.

2.4 Changes in design to avoid and reduce risks

The changes in design that are a result of the review process are summarised as follows:

- Nakra weir and transfer tunnel inlet portal have been moved further upstream than initially planned in the feasibility study. This was in order to move the structures to a position which is less exposed to avalanche and debris flow (see section 4.1.1).
- Nakra transfer tunnel outlet portal: The tunnel was realigned compared to that proposed in the EPC Contractors alternative bid (near the dam). One of the reasons was in order to avoid areas exposed to avalanche and debris flow.
- The depth of the Nenskra dam's cut off wall was revised compared in order to extend through the full depth of the permeable alluvial deposits and to extend into Fluvio-glacial deposits of lower permeability– some 125 metres in depth. The original depth was 65 metres. This measure is to further mitigate the risk of internal erosion of the alluvial deposits underlying the dam structure.
- The design of the reservoir spillway has been modified compared to that initially proposed by the EPC Contractor's alternative bid. A tunnel spillway has been adopted as this is the soundest solution given the geology of the area.
- The powerhouse location has been modified compared to that initially planned in the feasibility studies. The powerhouse has been moved some tens of metres from the nearby torrent in order to be in an area that is not exposed to avalanche and debris flows.
- The Nakra weir design has been revised (as recommended by the E&S studies). Two large radial gates that are sufficient to enable sediment that accumulates in the head pond to be periodically flushed downstream to prevent blockage of the Nakra transfer tunnel and to maintain the sediment transport function of the Nakra.
- The Nakra transfer tunnel design has been revised (as recommended by the E&S studies). A gate is included in the design to enable the transfer tunnel to be closed when necessary. The tunnel will be closed when the Nenskra reservoir is spilling – this will ensure that there is no incremental increase in flood flow rates in the Nenskra valley compared to the natural situation as a result of the Nakra diversion. This will also allow the Nakra river natural flow rate to be re-instated periodically during flood event in order to maintain the sediment transport function of the Nakra.

3 Natural hazard risks in the Nenskra valley

This section is broken down into two subsections:

- Risk to assets and personnel, deals with the risk that natural hazard risks events could affect Project assets and personnel, including temporary construction worksites, accommodation camps and technical facilities and during both construction and operation.
- Risk to communities, deals with the risks that communities downstream from the dam could be affected by knock-on effects of accidental events at the dam triggered by natural hazards events, and the risk of reservoir triggered seismicity.

3.1 Risks to assets and personnel

3.1.1 Overview

3.1.1.1 Natural hazard risk assessments

The Project has undertaken a natural hazards risk assessment to identify and characterise natural hazards that are present in the Project area and which could affect Project components. This study is considered as a safeguard measure and is referred to later in this report as:

- [SAF 1] Natural hazard risk assessment.

With regard to the temporary construction camps and technical facilities, the Project has undertaken a preliminary natural hazard assessment. This study is considered as a safeguard measure and is referred to later in this report as:

- [SAF 2] Construction camp and technical installations preliminary natural hazard risk assessment.

Additional studies will be undertaken for the temporary construction camp to further assess risk, design protection measures, design monitoring and develop an Emergency Preparedness Plan. A risk register will be developed. The hazards to be assessed and for which avoidance and protection measures will address include the following: avalanche, rockfall, debris flow, landslide, and flooding. These actions are considered as a safeguard measure and are referred to later in this report as:

- [SAF 3] Detailed natural hazard risk assessment for all construction camps and technical installations to be completed before camps and installations constructed.

The findings of the natural hazards risk assessment are summarised in Table 2. It should be noted that the risk applies to both assets and personnel. The method that has been used to estimate the risk levels is provided in Annex 3 and follows the method recommended by ICOLD.

In the following subsections 3.1.2 – to 3.1.9 are provided the descriptions of the natural hazard risks for the different project components situated in the Nenskra valley.

3.1.1.2 Seismic studies

With regard to seismic risks, detailed geological and seismic hazard studies have been undertaken during the Project Feasibility Study and Basic Design in order to ensure that the dam structure is built to withstand the Maximum Credible Earthquake (MCE), which is 7.5 on the Moment Magnitude Scale (About 7.2 on the Richter scale), with a return-period of 10,000 years. The MCE determined by the EPC Contractor has been through a review process by the Owner’s Engineer, the Lender’s Technical Advisor and the IPoE on dam safety. In addition, the Project has adopted seismic design criteria for buildings and facilities at the dam site, operators village and the powerhouse that are in alignment with Georgian seismic construction codes and standards, and Good International Practice. These safeguard measures are referred later in this report as:

- [SAF 4] Earthquake hazard assessment, definition and design of dam structure to withstand Maximum Credible Earthquake
- [SAF 5] Adoption of seismic design criteria for buildings and facilities at the dam site, operator’s village and powerhouse that are in alignment with Georgian seismic constriction codes and standards and Good International Practice.

3.1.1.3 Hydrological studies

Hydrological studies have been undertaken during the Project Feasibility Study in 2012 and during the Basic Design in 2015-16 in order to design the scheme for optimised energy generation and without compromising the safety of local communities. The hydrological studies include evaluation of flood peak discharges. These are determined in order that the dam’s operating rules can be defined and to ensure that the flood control structures are designed with sufficient capacity to guarantee the safety of the dam. The Probable Maximum Flood (PMF) has been determined and the flood control structures are being designed to evacuate safely the PMF. The PMF determination determined by the EPC Contractor has been through a review process by the Owner’s Engineer, the Lender’s Technical Advisor and the IPoE on dam safety. This safeguard measure is referred later in this report as:

[SAF 6] Hydrological studies, definition of PMF and flood control designed to evacuate PMF.

The Project recognises that climate change may influence the PMF in the long term and consequently a climate change risk assessment has been commissioned by JSCNH and is currently ongoing. Any increase in the value of the PMF due to forecast climate change will be address through design, and the dam flood control structures design will be revised to accommodate safely the revised PMF if required. This safeguard measure is referred later in this report as:

- [SAF 7] Climate changes taken into account in determining PMF – and design of flood control structures.

Table 2 : Level of potential natural hazard risk to assets and personnel in the Nenskra valley

Component / Hazard	Floating debris	Ava-lanche	Debris flow	Rockfall	Slope in-stability	GLOF	Earth-quake*	Extreme flood
Permanent facilities								
Nakra transfer tunnel outlet				Pr				
Dam and reservoir		Pr	Pr				D_e	D_f
Bottom outlet		Pr	Pr					
Spillway	Pr	Pr	Pr					D_f
Headrace tunnel portals								
Penstock								
Powerhouse			AS					
Temporary facilities								
Dam camp		Pre	Pre	Pre	Pre			
Powerhouse camp		Pre	Pre	Pre	Pre			

Key	Not Applicable	Low	Moderate	High

Pr	Protection measures will be designed and built in order to reduce residual risk to Low.
Pre	Preliminary assessment. Additional studies will be undertaken to further assess risk, design protection measures, design monitoring and develop an Emergency Preparedness Plan in order to reduce residual risk to Low.
De	Earthquake risk mitigated through design and residual risk is low (see section 3.1.1.2).
Df	Flood risk mitigated through design and residual risk is low (see section 3.1.1.3).
AS	Additional studies required, to confirm

* Includes Reservoir Triggered Seismicity

3.1.2 Nakra transfer tunnel outlet portal

A. Description of hazard

During the Basic Engineering, the proposed position of the portal was moved 3 kilometres upstream from the position initially planned near the dam, to a location near the tail of the reservoir which is less exposed to avalanche and debris flow hazards. However, the portal is located in a rock wall, and there may be the risk of local rockfall.

B. Safeguards to mitigate risk to structures and personnel

The rockfall risk is not an issue in terms of dam safety; however, the design will need to include protection measures for the structure and for workers during construction work.

These safeguard measure is referred later in this report as:

- [SAF 8] Nakra transfer tunnel outlet portal structure protected from potential rockfall. The protection measures are included in the design and installed during construction.

- [SAF 9] Nakra transfer tunnel outlet portal worksite and construction workers are protected from potential rockfall. The protection measures are included in the design and installed at the start of the construction.

Figure 2 – Location of Nakra transfer tunnel outlet portal

3.1.3 Nenskra dam and reservoir

3.1.3.1 Overview

The Nenskra dam and reservoir are exposed to a number of natural hazards as illustrated by the map below and described in the following subsections.

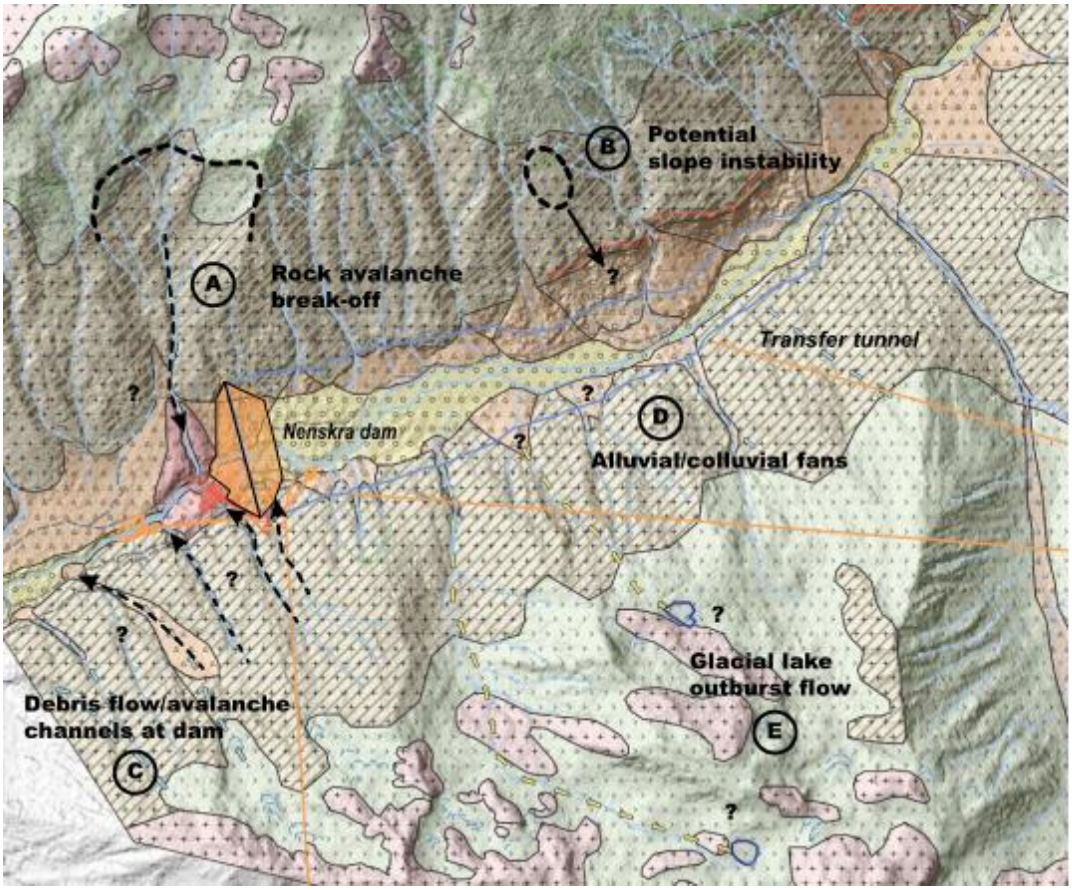


Figure 3 – Geomorphology of the Nenskra reservoir – indicating major hazards

3.1.3.2 Deep-seated landslide/debris flow at dam site

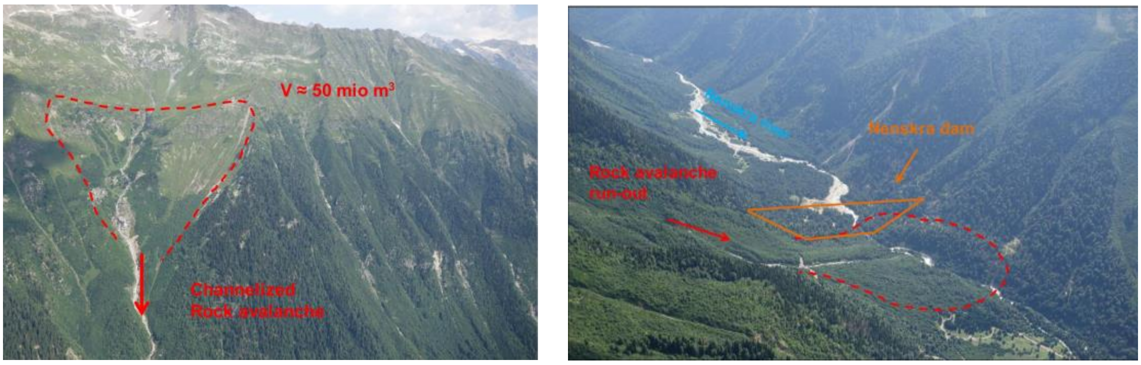
A. Description of hazard

The dam resides partially on post-glacial deposits originating from a deep-seated landslide event that was followed by regular debris flow events triggered by rainfall (see Figure 3). The deposits on the valley floor where detached from the upper right slope above the right dam abutment, and deposited immediately downstream of the current dam emplacement, running up on the opposite, left valley slope. The slope collapse was probably due to the presence of destabilizing, slope-parallel, sheet or exfoliation joints that can be observed in the area of where the landslide occurred.

Figure 4 below shows the detachment and deposition areas. **The possibilities of further slope collapses are considered low** according to an inspection of the possible source areas by means of a satellite image inspection and helicopter overflight and a slope stability assessment using satellite radar interferometry (see Annex 5 and section 3.1.3.4).

B. Safeguards to mitigate risk to structures and personnel

Although the possibility of landslide is low, the stability of the slope will be monitored. If the monitoring identifies a risk of landslip the reservoir water level will be lowered as a measure to reduce the likelihood of potential dam failure (see section 5.1 - Table 9 – safeguards for initiating event 2).



Visual evidence of an historical landslide deposit at the dam emplacement. Left: View from the left bank towards the detachment zone of the landslide event. The volume of the material is probably significantly less than 50 million cubic metres. Right: Maximum extension of the landslide and run-up area on the opposite slope.

Figure 4 – Historical evidence of landslide at the dam site

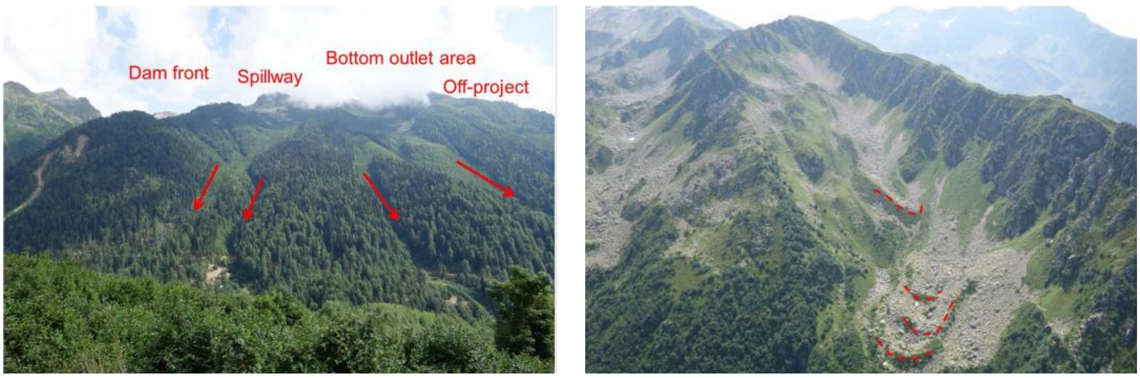
3.1.3.3 Debris flow and avalanche at the dam

A. Description of hazard

The dam and appurtenant structures are exposed to potential debris flows events.

On the left bank (see Figure 3). There are 3 alluvial/debris channels which align (i) with the upstream dam face in the left abutment, (ii) the downstream dam face or spillway area and (iii) the Bottom outlet tunnel portal area. A forth channel probably points downstream of the project area (Figure 5).

On the right bank – immediately downstream from the dam axis – there is an unnamed torrent that flows into the Nenskra at a location which corresponds to what will be the lower slopes of downstream side of the dam. The torrent is subject to avalanches in winter and local people confirm that snow avalanches with varying intensity happen every year. In 1987, which was a year with particularly heavy snow falls, a large avalanche occurred blocking the valley at that point. However, the valley is very narrow at that location, and blocked lower section of the valley was approximately 200 metres wide.



Debris flow/avalanche channels on the left slope above the dam (left) and uphill area of the rightmost channel (right).

Figure 5 – Debris flow/avalanche channels in the area of the dam

B. Safeguards to mitigate risk to structures

The design of the dam structure will take into account these hazards:

- Avalanche and debris flow hazards are common issues that are successfully managed in the hydropower industry. For the right bank avalanche/debris flow hazard technical solutions are understood and available and could comprise for avalanche, the installation of avalanche protection barriers and/or systems to trigger small avalanches safely to prevent the build-up of snow or alternative measures. Similarly, for debris flow cable mesh systems or similar can be installed. However, the selection of the protection and prevention measures (which could include changes to the design) will be subject to a further study. See section 5.1 - Table 9 – safeguards for initiating event 2) - [SAF 32] Measures to mitigate external erosion of the dam structure from avalanche and debris flow events.
- The left bank channel which points to the upstream face of the dam is rather small and is probably not directly linked to the uphill source area. It probably transports mainly water and only little rock and soil material. However, it can be the source of avalanches, which may bring in trees and other hazardous debris. Since this channel points into the reservoir, it presents a hazard for the Bottom outlet portal and the Headrace tunnel portal. The incoming material will be stopped by a collector.
- The remaining left bank channels (on the downstream face of the dam/spillway area, Bottom outlet exit portal) are larger and may have a more direct connection to the upstream source areas. Since these channels do not interfere with the reservoir basin, they should have the possibility to discharge along an open channel.

The safeguard measures in terms of dam safety are described in section 5.1 - Table 9 – safeguards for initiating event 2).

C. Safeguards to mitigate risk to personnel

In terms of construction worker safety, the protection measures will be to install the dam, spillway, bottom outlet and headrace portal avalanche/debris flow protection structures at the start of construction in order to protect construction workers, to install avalanche/debris flow monitoring devices, prepare procedures that construction work is to be stopped when there is a risk of avalanche or debris flow, and that a construction emergency preparedness plan is developed before the start of construction. This safeguard measure is referred to later in this report as:

- [SAF 10] Dam site, bottom outlet, spillway and headrace portal worksites and construction workers are protected from potential avalanche/debris flow events. The protection measures are included in the design and installed at the start of the construction.
- [SAF 11] Monitoring, early warning system and identification of safe areas of avalanche and debris flow risk at the dam site, bottom outlet, spillway and headrace portal worksite worksites during construction and operation.
- [SAF 12] Construction emergency preparedness plan developed and will include procedures for stopping work at worksites if monitoring indicates a risk of avalanche or debris flow events. Plan will also include response procedures.

During operation, the measures to protect the structure will also be affective to protect operation staff.

3.1.3.4 Potential slope instability

A. Description of hazard

A potential area of slope instability in the area of the future reservoir has been identified and evaluated. A field examination was made in August 2016 including a helicopter overflight. The area is located in the middle right slope approximately 2.5 kilometres upstream of the dam area (see Figure 3).

An aerial view of the area of interest is provided in Figure 6. The area extends from an altitude that is above the reservoir full supply level (1,440 metres asl) to the upper slope (2,330 metres), where the vegetation changes from forest to grass land. The change in vegetation coincides with a change in slope inclination and geological conditions:

- The lower, forested part is steeper (40 degrees) and is composed of bedrock with a variable soil cover made of a mix of glacial deposits and slope debris.
- The upper, grass covered part is less inclined (30 degrees), its substratum is composed of sub-outcropping bedrock with a thinner soil cover principally made of glacial deposits and pre-glacial erosion remnants.

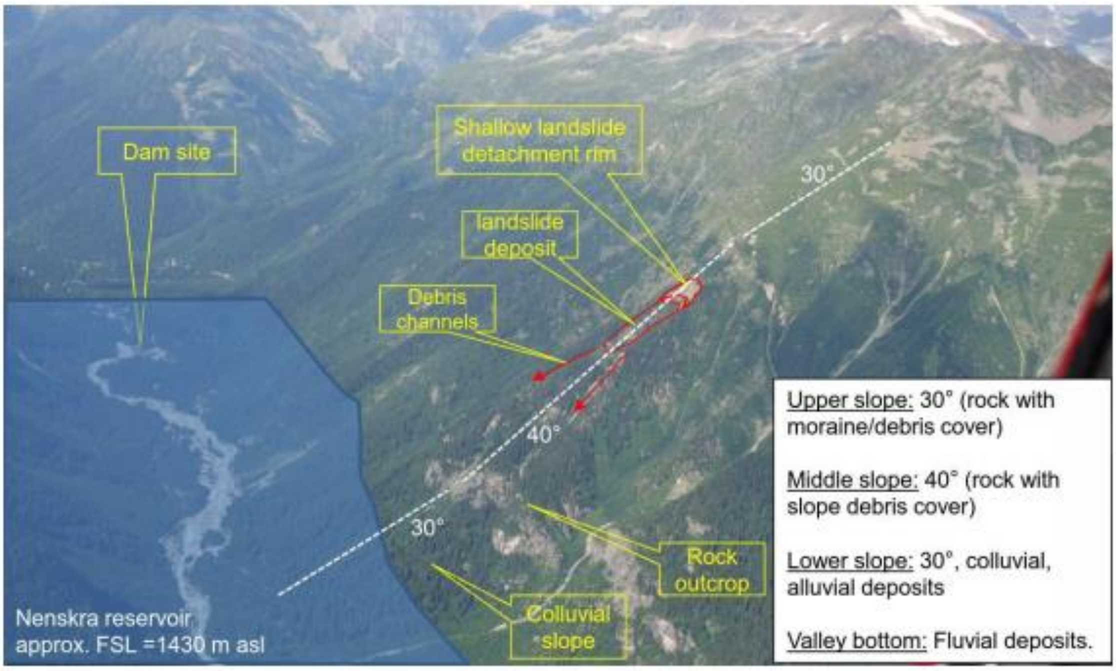


Figure 6 – Aerial view of the area of uncertain slope stability

A summary of the assessment of the slope stability is provided in Annex 5. The overall conclusion is that there is no evidence to suggest the possibility of general, larger-scaled slope instability. The volume of the unstable material is significantly smaller (by a factor of at least 15,000) than the volume of the reservoir. Two possible slope instability scenarios have been studied to evaluate the consequences of a small superficial landslide on the reservoir and dam:

- Scenario 1: Decomposition of the landslide mass by debris flows that travel along the debris channels. A volume of 10,000 cubic metres is considered.
- Scenario 2: Rock mass break-offs of 10,000 cubic metres from the frontal rock face.

Both scenarios may cause impulse waves in the reservoir. The methodology developed by SFOE (2009) has been used to assess the potential of such impulse waves to overtop the dam and it has been found that the maximum run-of at the dam is 3.3 metres, whereas the freeboard in 6 metres, and consequently no dam overtopping from slope instability events is expected.

B. Safeguards to mitigate risk to structures and personnel

Even though the risk of slope stability is ranked as low, monitoring of the slope stability carried out (see section 5.1 - Table 8 – safeguards for initiating event 3: creation of large impulse wave in the reservoir).

3.1.3.5 Alluvial/colluvial fans

A. Description of hazard

There are a number of lateral alluvial/colluvial fans and channels that reach into the future reservoir. They present a two-fold hazard:

- Debris flows and avalanches may travel along these channels and impact the reservoir, causing impulse waves and also bring in floating debris that may present a hazard for the dam and spillway.
- The alluvial/colluvial fans may be unstable due to submergence and reservoir draw-down.

The findings of the assessment of these hazards are as follows:

- With regard to the risk of creation of impulse waves from land slide or debris flow, the landslide volumes which may be destabilized in a draw-down context are generally not capable to trigger a pulse wave which is larger than the reservoir level reduction and thus cannot overtop the dam. For a debris flow entering the reservoir at a distance of 100 metres from the dam, the size of a resulting impulse wave has been calculated and the run-up at the dam has been calculated to be 3.1 metres, whereas the freeboard is 6 metres. Consequently, dam overtopping is not expected.
- With regard to an impulse wave generated by an avalanche, the Project will undertake avalanche studies to determine the volume of snow potentially mobilised and the size of a resulting impulse wave in order that mitigation measures can be defined (see part B below). However, the reservoir is planned to function with maximum supply level in November and that during the period November to April, the reservoir water level will be progressively lowered and will be at minimum operating level in April. Consequently, during the period when avalanches are most likely, the reservoir will not be at full supply level and the likelihood of an eventual impulse wave overtopping the dam is reduced.

Typical situation of a alluvial/colluvial fan which will be submerged by the reservoir and subject to reservoir draw-down (left) and soil structure of such a fan, composed of large-scale granular material (cobbles to blocks) in a sandy-gravelly matrix (right).

Figure 7 – Submerged alluvial/colluvial fans

B. Safeguards to mitigate risk to structures and personnel

The alluvial/colluvial fans which are within a few hundred meters of the dam will be analysed for avalanche and debris flow activity to determine if there is a threat to the bottom outlet, spillway, and dam structure which could lead to a dam failure event. This commitment is referred later in this report as: (see section 5.1 - Table 8 – safeguard for initiating event 2).

In addition, a study will be undertaken with regard to the risk of avalanche generated impulse waves and dam overtopping and modifications to the Project design if necessary to mitigate the risk. This commitment is referred to later in the report as:

- [SAF 13] Risk assessment with regard to avalanche generated impulse waves, dam overtopping and eventual changes in Project design, if necessary

Draw-down effects have been considered taking into account the available geological information. The assessment has found the potential for draw down to trigger instabilities that may overtop the dam to be negligible and consequently no mitigation measures are planned.

3.1.3.6 Area upstream of Nenskra reservoir

A. Description of hazard

A high-level assessment of the area upstream from the reservoir has been undertaken. The assessment has been based on interpretation of topographical maps, satellite imagery and helicopter fly over. The purpose of the assessment was to identify possible risks for the operation of the Nenskra HPP, particularly the reservoir and the dam and appurtenant structures. Upstream of the reservoir end, the Nenskra valley continues linearly for another 4 kilometres in a NNE direction, then the valley forks up into 2 smaller valleys at 1,650 metres asl. The 2 valleys are E-W and SW-NE aligned and terminate after roughly 10 and 14 kilometres, respectively. The geomorphology and hazards and risks of the area upstream of the reservoir end can be described as follows.

- A larger alluvial fan enters from the left slope about 800 metres upstream of the reservoir end and leads to a larger lateral valley. According to the morphology and vegetation the fan does not seem to be active.
- Another alluvial fan is entering from the left slope about 2.2 kilometres upstream of the reservoir end (Figure 8). According to the reporting of the local population, the corresponding upstream slope instability was (re-) activated during the snow-melt after the avalanche winter of 1986/1987. The superficial slope instability is active and probably produces regular debris flow phenomena.

The area of confluence shows that the inflow channels that may bring debris into the fan area have a width of about 10 metres and a depth of a few meters. The river Nenskra flows around the alluvial fan in a flat channel of 10-20 metres width.

B. Safeguards to mitigate risk to structures and personnel

Even though the risks originating from this situation are considered low for the Project components, monitoring will be carried out to observe the situation at the confluence regularly, particularly in the early summer, after the snow melt (see section 5.1 - Table 8 – safeguards for initiating event 3: creation of a large impulse wave in the reservoir.

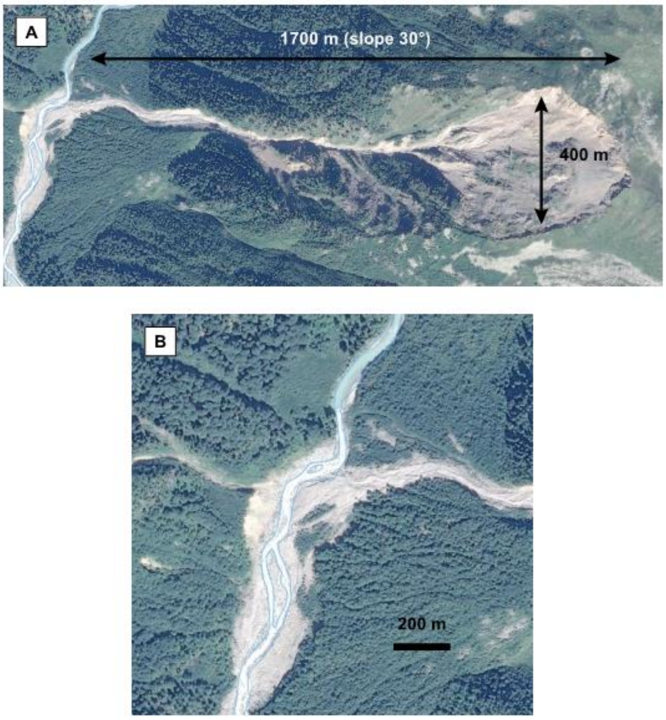


Figure 8 – Area 2.2 kilometres upstream of reservoir end. Overview (A) and detail at the confluence with the river Nenskra (B).

3.1.4 Reservoir spillway

A. Description of hazard

A.1 Avalanche and debris flow

The reservoir spillway will be a tunnel spillway. It is well protected against surface processes such as avalanches, debris flows and spontaneous earthquake-triggered soil slides, but is vulnerable to clogging from floating debris. However, the spillway inlet is a risk of blocking from avalanche and debris flow events and protection measures will be included in the design.

Alluvial/debris fans with possible debris flow and snow avalanche activity which point towards the upstream face of the dam (left) and the initial and middle/final part of the surface spillway (right).

Figure 9 – Reservoir spillway – and avalanche and debris flow channels

A.2 Glacial lake outburst floods

Glacial lake formation is currently observed in the majority of glaciated mountain regions of the world such as the Himalayas, Andes, Alps, etc. Often dammed by ice-cored moraines, glacial lakes can be the cause of Glacial Lake Outburst Floods (GLOF).

The Project's natural hazard risk assessment – which included a field visit in August 2016 with a helicopter fly-over - included the assessment of GLOF risks.

This safeguard measure is referred later in this report as:

- [SAF 14] Natural hazard risk assessment – evaluation of GLOF risks.

The few glacial lakes that could have an effect on the Project components are located on top of the left-hand slope above the reservoir - their characteristics are shown in Table 3. Even though the volumes may be considerable (estimated volumes of 40,000 and 50,000 cubic metres), the routing distance down to the reservoir is long (1.5 and 3.5 kilometres) and flood waters would enter into the reservoir at a distance of 1.2 to 1.8 kilometres from the dam site.

Consequently, there may be the risk of the transported fine material could clog the Bottom Outlet or transported floating debris to block the spillway.

Table 3 : Characteristics of the two lakes of glacial origin in the upstream catchment

Estimated lake volume (m^3)	Routing distance to reservoir (km)	Distance from dam at impact (km)
50,000	3.5	1.2
40,000	1.5	1.7

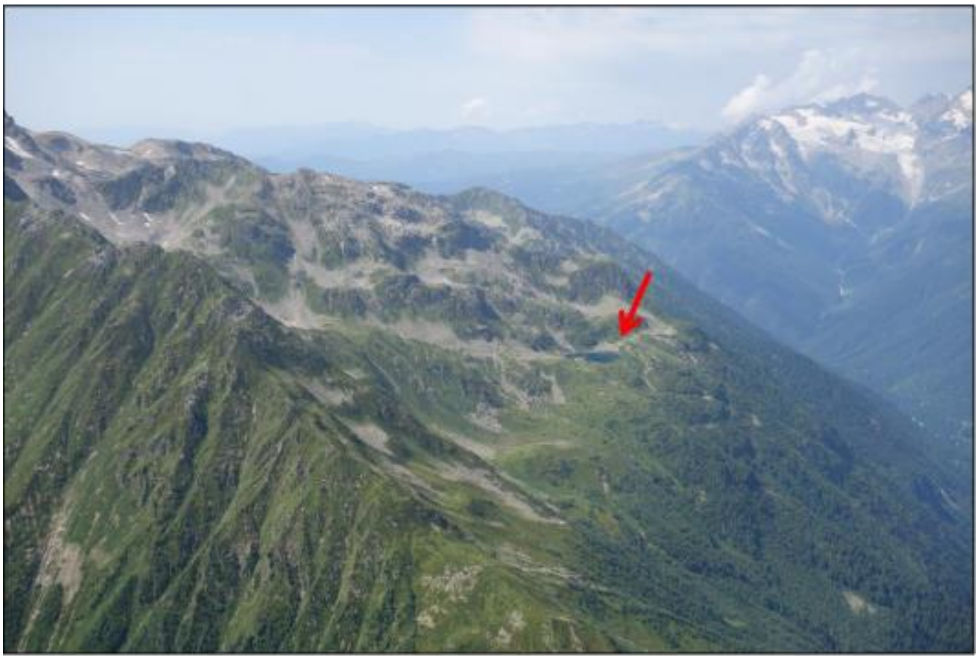


Figure 10 – Photograph of one of the glacial lakes in the reservoir catchment

A.3 *Floating debris*

Floating debris (mainly plants and trees) may be transported into the reservoir regularly and especially during natural hazard events (heavy rainfall, flood, debris flows, landslides, rockfall and snow avalanches) and may clog or damage the spillway. The probability of spillway clogging can be reduced through protection measures to keep floating debris at a distance - such as a log boom. Residual risks to the dam (including overtopping) from partial spillway blockage, taking this mitigation into account, are being addressed in the design of the dam. It will be ensured that the final design, including with regard to the capacity of the bottom outlet and spillway, will be able to safely pass the PMF taking into account reduced functionality of the spillway. This is standard practice for large dams and the solution will be verified by the IPOE before the project is constructed.

B. Safeguards to mitigate risk to structures and personnel

B.1 Safeguards to mitigate risk of avalanche and debris flow

The safeguards for the structure are described in section 3.1.3.3B (and referenced in section 5.1 - Table 9 – safeguards for initiating event 2).

The safeguards for personnel are described in 3.1.3.3C and comprise [SAF 10], [SAF 11], and [SAF 12].

B.2 Safeguards to mitigate risk of GLOF

The safeguards for the structure comprise system to protect the spillway from floating debris and is referenced in section 5.1 - Table 8 – safeguards for initiating event 2).

GLOF's are rare events and therefore are not normally considered in relation to construction risks.

B.3 Safeguards to mitigate risk blockage from floating debris

The safeguards for the preventing blockage of the spillway from floating debris is referenced in section 5.1 - Table 8 – safeguards for initiating event 2).

3.1.5 Bottom outlet

A. Description of hazards

A.1 Avalanche and debris flow

The Bottom Outlet's inlet and outlet portals are both situated in areas potentially affected by alluvial/debris fans with possible debris flow and avalanche activity. The inlet portal in particular is at risk of clogging due to floating debris (heavy rainfall, avalanches) and debris flow material. The design of the structures will take account of these possible hazards as the bottom outlet is a safety feature allowing the reservoir water level to be lowered if a safety issue arises, and blocking the bottom outlet would also stop the ecological flow leading (to environmental consequences).


The intake portal of the Bottom outlet tunnel is located at the foot of the snow-covered debris fan on the right of the photograph (left). The alluvial/debris fan with snow avalanche activity which points towards the area of the exit portal of the Bottom outlet tunnel (right).

Figure 11 – Bottom outlet inlet and outlet portals

A.2 Glacial lake outburst floods

The bottom outlet is potentially blocked by a GLOF in the same way as the spillway described in section 3.1.4.

B. Safeguards to mitigate risk to assets and personnel

B.1 Safeguards to mitigate risk of avalanche and debris flow

The safeguards for the structure are described in section 3.1.3.3B (and referenced in section 5.1 - Table 9 – safeguards for initiating event 2).

The safeguards for personnel are described in 3.1.3.3C and comprise [SAF 10], [SAF 11], and [SAF 12].

B.2 Safeguards to mitigate risk of GLOF

GLOF's are rare events and therefore are not normally considered in relation to construction risks and it is not feasible to construct protection structures. Nevertheless, the risk of GLOF will be monitored (see section 5.1 - Table 9 – safeguards for initiating event 2).

3.1.6 Headrace tunnel portals

A. Description of hazards

The upstream portal at the Nenskra dam is located in the predominantly crystalline basement lithologies of the Nenskra Complex. The downstream portal is located in the Upper Sori Formation (alternations of sandstone and clayshales), which may be prone to rockfall or general slope instability.

A preliminary analysis of the geological, geomorphological and topographic situation shows:

- The currently chosen location of the intake portal is in a bedrock outcrop. The possible hazards of snow avalanches, debris flows and local rockfall appear to be negligible.
- The exit portals (tunnel boring machine mount tunnel portal and Headrace exit portal) are both located in forested hill slopes. The respective morphological situations are favourable with respect to possible hazards: Slope instabilities such as landslides and channelized phenomena such as debris flows and snow avalanches are unlikely to be a problem.

B. Safeguards to mitigate risk to assets and personnel

No safeguards with respect to natural hazards are necessary.

3.1.7 Surge shaft and penstock

A. Description of hazards

The surge shaft is located nearly at the top of a morphological crest and not exposed to natural hazard risks.

The penstock follows the same, densely forested, morphological crest. No torrents are crossed, the bedrock is probably mainly dry. The bedrock is formed of rocks from the Upper Sori Formation, a lithology composed of alternations of sandstone and clayshales, of which the sandstones appear to be dominating. The bedrock is sub-outcropping (usually the bedrock is outcropping or covered by up to 1 metre soil, in topographic channels the soil cover may reach approximately 2-3 metres) along the complete alignment of the penstock. Only in the final part of the slope, towards the powerhouse, the soil cover (talus slope) may reach 5-10 metres. A preliminary analysis of the geological, geomorphological and topographic situation shows:

- The general slope stability appears to be good due to the generally counter-slope oriented stratification. In a few occasions, very persistent discontinuities could be observed. They are present particularly in the areas where the penstock follows the morphological crest and need attention. Local sliding and wedge instabilities may be an issue.

- There may be situations of isolated rockfall, they need to be analysed accordingly.
- Other hazards are of limited importance and unlikely due to the topographical situation.

B. Safeguards to mitigate risk to assets and personnel

The design will need to include protection measures for the structure and for workers during construction work. These safeguard measure is referred later in this report as:

- [SAF 15] Penstock structure protected from potential rockfall. The protection measures are included in the design and installed during construction.

- [SAF 16] Penstock worksite and construction workers are protected from potential rockfall. The protection measures are included in the design and installed at the start of the construction.

3.1.8 Powerhouse

A. Description of hazards

The powerhouse is located close to the exit of a smaller valley with a hydrographic basin of 1.9 square kilometres and maximum elevations around 1,750 metres asl (Figure 12).

The bedrock is formed of the Upper Sori Formation (sandstones, clayshales), Lower Khojali Formation and the Middle Khojali Formation (volcanics). Particularly the lithologies of the Upper Sori Formation appear to be prone to produce source material for geological hazards, such as granular debris flows.

A preliminary analysis of the geological, geomorphological and topographic situation shows that there may be possible sediment transport/debris flows during periods of heavy rainfall along the lateral torrent and at the exit of the upstream valley.

Figure 12 – Aerial view of the powerhouse area and smaller valley above

B. Safeguards to mitigate risk to assets and personnel

The powerhouse position was moved during the basic design by several tens of meters downstream, away from the torrent. It may thus be out of the reach of possible debris flow hazards. Snow avalanches and rockfall are not expected to affect the powerhouse.

Further hazard studies will be undertaken to confirm the expected low risk of debris flow, and if necessary protection measures will be defined and built. This safeguard measure is referred later in this report as:

- [SAF 17] Study to confirm debris flow risk at the powerhouse and if necessary define protection to be included in the design and built to protect the powerhouse, construction site and construction workers.

3.1.9 Construction camps and technical facilities

A. Generalities

The Project has undertaken a preliminary natural hazard risk assessment for construction camps and technical facilities. The overarching conclusion is that the camps and technical facilities are exposed to a moderate risk with regard to natural hazards such as avalanche, debris flow, rockfall and landslide. Consequently, the Project will undertake further studies as the Project moves forward and include in the design the necessary protection measures.

These safeguard measure is referred later in this report as:

- [SAF 18] Natural hazard protection measures to be included in the design of temporary construction camps and technical facilities to protect assets and workers.

B. Dam camp and technical installation

The layout of the dam camp and technical installation is illustrated in the sketch provide in Figure 13, and is situated approximately 2 kilometres downstream from the dam site.

Figure 13 – Sketch of dam camp and technical installation layout

The area where the camp is planned to be located is 1.5 kilometres downstream from the dam structure, it is located in a meadow where local people have constructed summer cabins. Local people report that in 1987 that the runout from an unusually large avalanche that occurred on the slopes above the meadow (on the right bank) extended across part of the meadow where the construction camp is planned to be located. Consequently, the risks for natural hazard events affecting the site are ranked as moderate and further studies will be undertaken to define the protection measures required. It should also be noted that the area earmarked for the construction camp is located 1.5 kilometres downstream from the area affected by the large avalanche that occurred in 1987 - near the dam site - and which blocked the valley which is very narrow at that point (see section 3.1.3.3A).

C. Powerhouse camp and technical installation

The natural hazards in relation to the powerhouse are described in section 3.1.8. The location of the powerhouse construction camp and technical installations are still being defined at the time of writing, though they will be in close to the powerhouse and consequently it has been possible to make a tentative estimate of the natural hazard risks – which are the same as those for the powerhouse. This will be confirmed when the location has been confirmed, and protection measures will be defined.

3.2 Risks to communities

This section describes the situations whereby high unexpected flows in the Nenskra River downstream from the dam could occur and which represent a risk in terms of community safety. The situations which are discussed include rare accidental situations resulting from naturally occurring hazardous events, malfunction of control systems, or human error.

3.2.1 Reduced risk of flooding from natural flood events

The presence of the dam-reservoir has a positive impact in terms of reducing natural flood events, or from GLOF, or floods from the breaching of natural dams forming in the upper catchment; as they will be mostly stopped by the reservoir. In the event of a natural flood event, the reservoir will in many cases be able to contain some or all of the flood waters before the reservoir water level reaches the full supply level and spillage occurs. The reservoir also has a buffering effect and will reduce the floods peak flow. This reduction and buffering will be most noticeable for the more frequent and smaller flood events. In the same way, the monitoring tools that will be installed to early identify avalanches or debris flows will benefit to people during the construction & operation phase.

3.2.2 Accidental flow events

3.2.2.1 Bottom outlet gate malfunction

A. Description of the event

The bottom outlet gate system comprises two gates in series which comprise a guard gate and a service gate. This configuration is itself a safety feature.

The bottom outlet gates are normally maintained closed. The gates are a safety feature that when opened allow the reservoir water to be released and the reservoir water level to be lowered. The gates are designed to discharge reservoir water at a maximum flow rate of 200 m^3/s, which is equivalent to a 100-year return period flood event. The operation of the gates will be subject to strict operating rules and procedures. Situations when the bottom outlet can be expected to be opened are as follows:

- Venting of sediments that have accumulate in the reservoir;
- In the case of suspected degraded dam stability as described (see section 5.1). The reservoir water level is lowered so that the dam can be inspected and remedial measures undertaken;
- When monitoring detects a risk of slope instability or avalanche. The lowering of the reservoir water reduces the likelihood of damage occurring to the dam as a result of an impulse wave;
- In the case of the blockage or insufficient capacity of the spillway, and
- During the annual testing of the bottom outlet gates.

The malfunctions that could occur with respect to the operation of the gates could be caused by either human error, or a control system malfunction. The presence of sediment preventing the closing of the gate once it has been opened is a recognised malfunction in the hydropower industry, but in the case of Nenskra the bottom outlet conduit is 4 metres in diameter and the likelihood of this type of malfunction is considered very remote. The malfunctions are as follows:

- Opening too much when intended to open a small amount;

- Not closing when open and intended to close, and
- Opening fully when should be maintained closed.

The above malfunctions would result in a high uncontrolled flow rate in the Nenskra River downstream from the dam. The maximum flow rate of the discharge in the case of a malfunction of the safety systems that control the maximum allowed discharge can potentially be as high as 317 m^3/s.

B. Consequences and safeguards

As the Project moves forward a detailed risk assessment of the bottom outlet gate operation will be undertaken in alignment with ICOLD methodologies. This measure is referred later in this report as:

- [SAF 19] Bottom outlet gate operation risk assessment in alignment with ICOLD methodologies.

The safeguard measures that will be used to minimise the risk of the above malfunctions are as follows:

- Strict, robust gate operation rules will be established and procedures for controlled operation of the gate will be developed;
- The gate will be subject to an inspection and preventive maintenance programme;
- The correct functioning of the gate will be checked annually, the gate will be opened a small amount and then closed again and remedial maintenance carried out in the event that the gate does not function correctly;
- Control and power systems will include an independent safety backup system;
- Gate will be equipped with a system for staged opening, with repeated actions required by the operator at each stage.

In subsequent section of this report these measures are referred to as:

- [SAF 20] Measures to mitigate risk of bottom outlet gate malfunction.

As the Project moves forward flood modelling of dam rupture and bottom outlet gate opening (including in the case of malfunction) will be undertaken and used in the preparation of the EPP and communicated to local communities. The flood mapping for the different scenarios considered in the modelling will be prepared and will include; dam failure; bottom outlet opening at 200 m^3/s, bottom outlet malfunction and release of 317 m^3/s, selected natural flood events – that overflow the riverbed - and which will be defined during the flood study. This measure is referred later in this report as:

- [SAF 21] Flood study downstream of the dam for the case of dam failure, full and partial bottom outlet opening, natural flood events and include early warning mechanism.

Measures to inform and protect local communities from this type of event are described in "Volume 3 – Social Impact Assessment" – in the section Community Health and Safety.

3.2.2.2 Impulse wave in the reservoir

A. Description of the event

A naturally occurring hazardous event such as slope instability or avalanche could create an impulse wave in the reservoir[5]. If large enough, the wave could overtop the dam causing the dam to fail (see section 5.1). However, slope stability studies have concluded that it is not realistic that this type of scenario could occur. However, if the slope instability or avalanche occurs when the reservoir is at maximum operating level, the resulting wave may result in spillage of reservoir water via the spillway, even if the wave is not of sufficient size to overtop the dam. This type of event could cause a sudden and unexpected flow of water in the Nenskra River downstream from the dam.

B. Safeguards

The safeguard to minimise the risk of the creation of a large wave in the reservoir as a result of avalanche or slope instability are discussed in section 5.1.

3.2.3 Reservoir triggered seismicity

A. Description of the hazards

Reservoir Triggered Seismicity (RTS) is of concern for two reasons; firstly, with respect to dam stability and the need for the dam criteria to take into account seismic load including those resulting from RTS, and secondly regarding the impact of RTS on the local communities. The Project's Earthquake Hazard Analysis includes an assessment of RTS and a summary is proved in Annex 4. This safeguard measure is referred later in this report as:

- [SAF 22] RTS assessment.

The conclusion of the RTS study is that when considering the natural stress environment of the Nenskra reservoir and the nature of the underlying rocks, the conditions appear relatively favourable for minimising the scale of potential RTS at the Nenskra reservoir. However, the possibility of occurrence of some RTS cannot be fully excluded and events with a magnitude of 4.5 or less on a Moment Magnitude scale (equivalent to 4.5 on the Richter Scale) and possibly slightly more must be regarded as possible. To put this into context, earthquakes with a magnitude in the range of 3 to 3.9 are classed as "minor" and magnitudes in the range of 4 to 4.9 are classed as "light". Seismic events in the range of 2.5 to 5.4 are often felt, but do not cause damage. Therefore, any RTS events will be of little consequence – if any – for the dam itself. The maximum magnitude of a RTS event will be inferior to that of the OBE-1 and MCE for which the dam structure is designed to resist, i.e. an RTS event cannot mechanically exceed natural seismicity.

Nevertheless, the Nenskra dam is in an area prone to seismic activity and any seismic events experienced in the region in the first few years after impoundment could be attributed to RTS whether true or not. This effect cannot be easily mitigated but it is a risk that is recognised by the Project Company. In terms of consequences of RTS on local communities, an RTS with a magnitude less than 4.5 is not expected to cause damage to buildings or structures.

[5] Inflow from a GLOF event would result in a situation similar to that of a flood event, and generation of an implulse wave is not expected.

B. Safeguards

As the study moves forward a detailed geological mapping of the faults near the dam site and an assessment of their neotectonic activity is programmed. This safeguard measure is referred later in this report as:

- [SAF 23] Geological mapping of the faults near the dam site.

In addition, the two following measures will be undertaken:

- Monitoring of seismic activity especially during reservoir filling during first impoundment. There will be slowing of filling if increased seismic activity is detected. Filling will be at a rate of less than 12 metres water height per week, which has been reported in the earthquake hazard risk assessment as sufficiently slow to prevent RTS of Mw >5 occurring.
- Monitoring of seismic activity during operation, filling should be at a rate less than 12 metres per week. Most rapid filling is during period Mid-May to end of June, 50 metres in 6 weeks, rate of 8.3 metres per week.

These safeguard measures are referred later in this report as:

- [SAF 24] Reservoir filling at less than 12 meters per week increase in depth
- [SAF 25] Monitoring of seismic activities and slowing/stopping of filling if increased seismic activity is detected.

3.2.4 Dam failure

In the very unlikely event of dam failure, downstream communities will be affected. The unlikely chain of events that could lead to a dam failure and the safeguard measures are described in section 5.1. The emergency preparedness planning is described in section 5.4.

3.2.5 Exposure of reservoir bypass cattle track exposure to natural hazards

The Project will create a bypass cattle track to allow local people to continue to access the areas upstream of the reservoir and which would without the track be difficult to access.

In order to ensure that the users of the cattle track are not exposed to natural hazard risk, the Project will undertake a natural hazard risk assessment for the cattle track and control and the necessary mitigation measures will be designed and constructed to ensure people are not exposed to unacceptable levels of risk. The measures, which will be under the responsibility of JSCNH will complement the emergency preparedness plan for the operation phase (see section 5.4.).

3.2.6 Landslide events triggered by tunnelling operations

A. Background

The Project has undertaken an evaluation of the vibrations induced by the excavation of the required tunnels. The evaluation has been carried out in view of establishing if there is a risk of slope instability that could cause landslide events affecting communities, and if the vibrations from the tunnelling could disturb communities. The evaluation has estimated vibration intensity at the source and the attenuation with distance. Calculations are based on the state-of-the-art literature and international technical recommendations.

B. Vibrations generated by the tunnel boring machine

Vibrations generated by tunnel excavation using Tunnel Boring Machines (TBMs) are reported in literature. Examples of typical values for the predicted vibration at a distance of 100 feet (30.48 metres) which is known as the Reference Predicted Vibration (PPV_{ref}) are provided in the table below. For comparison, the same literature sources report that blasting generates vibrations greater than those generated by TBM by a factor a 100.

Table 4 : Literature values for predicted vibrations for tunnel excavation using TBM

PPV_{ref}	Unit	Reference
0.14	mm/s	Washington State Department of transportation - SR 520 Bridge Department and HOV Program, West Connection Bridge project - Final Construction Noise and Vibration Report. Expressed as 0.0058 inches/second in the source document.
0.4	mm/s	The prediction and mitigation of vibration impacts of tunnelling. D. Hiller, paper n.5, Proceedings of Acoustics 2011. Expressed as 0.0157 inches/second in the source document.

The Table 5 below provides the values of PPV_{ref} measured along a tunnel excavated by TBM at different locations and different geological formations. The values are much lower than 0.5-0.75 inches per second which is the threshold for damage to structure reported by the US Bureau of Mines (USBM) (Report of Investigations 8507).

Table 5 : Example of maximum steady state vibrations along a tunnel excavated by TBM

Location #	OB thickness (Feet)	Rock thickness (Feet)	Rock type	Structure	Max. steady state PV (Inches/second)	Frequency range (Hz)
1	57	160	Granodiorite	Fault zone, high angle intersecting shear sets	>0.008	3-28
2	57	160	Granodiorite	Fault zone, high angle intersecting shear sets	0.0046	<1-37
3	3	289	Granodiorite and mafic intrusive	Competent	0.0030	18-79
4	10	372	Granodiorite and mafic intrusive	Competent	0.0060	15-80
5	20	387	Granite and banded schist	Low angle NW dipping foliation competent	0.0020	13-81
6	20	364	Granite and banded schist	Variable foliated schist bands competent	0.0050	17-53
7	15	417	Quartzite and mafic intrusive	Competent	0.0020	15-99
8	15	417	Mafic intrusive and minor quartzite	Competent	0.0060	27-88

Source: North American Tunnelling '00 - Monitoring of TBM induced ground vibrations, M. Carnevale, G. Young, J. Hager.

C. Level of vibrations perceptible by humans and threshold for damage to structures

The USBM defines a perceptible level of steady state vibrations for humans as 0.0085 inches/s (0.21 mm/s) at a frequency of 3 Hz and greater than 0.01 inches/s (0.25 mm/s) for frequencies between 20 and 80 Hz. The perceptible vibrations by humans are much lower than the damages threshold for structures which is 0.5-0.75 inches/s. Consequently, vibrations lower than the perceptible threshold, must be considered negligible since these vibrations do not affect in any way the slope stability or structures.

D. Risk analysis and impact

The TBM while advancing generates vibrations much lower than threshold to damage structures and also lower than perceptible vibration by humans. The excavation by TBM generates very low PPV and therefore doesn't affect the stability of the slopes in Nenskra valley and doesn't increase the existing risks. The excavation by TBM doesn't affect people living in the surrounding area since the PPV at surface is negligible and lower than the perceptible vibration by humans.

E. Propagation of vibration

The propagation of vibration through average soil/rock media has been calculated using the following formula:

$$PPVequip = PPVref\ (\frac{100}{Drec})^{n}$$

Where:

PPV_{equip}	Predicted vibration at distance D_{rec}
PPV_{ref}	Reference PPV at 100 ft
D_{rec}	distance from equipment to the receiver in ft
n	Value related to the attenuation rate through ground (= 1.1)

The Table 6 below shows the value for PPV_{equip} for different D_{rec} values.

Table 6 : Propogation and attenuation of vibration through the ground

D_{rec} (ft)	D_{rec} (m)	PPV_{equip} (Inches/second)	PPV_{equip} (mm/s)
0	0	0.0157	0.4
100	30.48	0.0058	0.15
150	45.7	0.0037	0.094
200	60.96	0.0027	0.068
250	76.2	0.0021	0.053
300	91.44	0.0017	0.043
400	121.9	0.0013	0.033
500	152.4	0.0010	0.025
1000	304.8	0.0005	0.012

The values indicated in Table 6 indicate that at a distance greater than 500 feet (152.4 metres), the PPV is lower than the threshold perceptible by human beings, meaning there is no effect on the ground surface stability.

The PPV_{equip} at 100 feet and for distances greater than this are lower than the threshold appreciable by humans. Consequently, with this very low PPVs, no negative impact on slope stability is expected.

The PPV_{ref} predicted at the ground surface is much lower than the perceptible threshold by humans.

F. Conclusion

The evaluation has concluded that by considering the typical level of vibration from a TBM and taking into consideration the geology of the Nenskra site, and characteristics of the tunnels to be excavated, the predicted vibrations at ground level are much lower than vibrations that could generate slope stability problems or disturb communities.

4 Natural hazard risks in the Nakra valley

This section is broken down into two subsections:

- Risk to assets and personnel, deals with the risk that natural hazard risks events could affect Project structures and facilities, including temporary construction worksites, accommodation camps and technical facilities.
- Risk to communities, deals with the risks that communities downstream from the Nakra weir could be affected by an increase in a risk of flooding as a result of a reduced capacity for the Nakra to flush away sediment.

4.1 Risks to assets and personnel

4.1.1 Overview

4.1.1.1 Natural hazard risk assessments

The Project has undertaken natural hazards risk assessment, seismic studies, and hydrological studies to identify and characterise natural hazards that are present in the Project area including construction camps. These assessments are described in section 3.1.1.

The findings of the natural hazards risk assessment are summarised in Table 7. It should be noted that the risk applies to both assets and personnel. The method that has been used to estimate the risk levels is provided in Annex 3 and follows the method recommended by ICOLD.

Table 7 : Level of potential natural hazard risk to assets and personnel in the Nakra valley

Component / Hazard	Avalanche	Debris flow	Rockfall	Slope in-stability	GLOF	Earth-quake	Extreme flood
Permanent facilities							
Nakra weir and transfer tunnel inlet	Low	Not Applicable	Low	Not Applicable	Not Applicable	Low	Moderate D_f
Temporary facilities							
Nakra camp	Moderate Pre	Moderate Pre	Moderate Pre	Moderate Pre	Not Applicable	Low	Low

Key	Not Applicable	Low	Moderate	High

Pre	Preliminary assessment. Additional studies will be undertaken to further assess risk, design protection measures, design monitoring and develop an Emergency Preparedness Plan in order to reduce residual risk to Low
Df	Flood risk mitigated through design and residual risk is low (see section 3.1.1.3)

4.1.2 Nakra weir and transfer tunnel intake portal

The Nakra weir and transfer tunnel portal are exposed to potential avalanche and debris flow events, but the risk has been evaluated to be low.

The structures are located at the foot of a steep valley slope, covered by older tree vegetation. On both sides, the area is delimited by alluvial fans, which show a younger tree population, indicating past geomorphological activity due to avalanches and debris flows.

During the basic engineering the structures were moved about 100 metres upstream from the position initially planned during the feasibility studies. This was in order for the structures to be located in an area less exposed to avalanche and debris flow hazards. Doing so, the weir and tunnel portal are located in the central part of the area, making them safe from avalanches or debris flows.

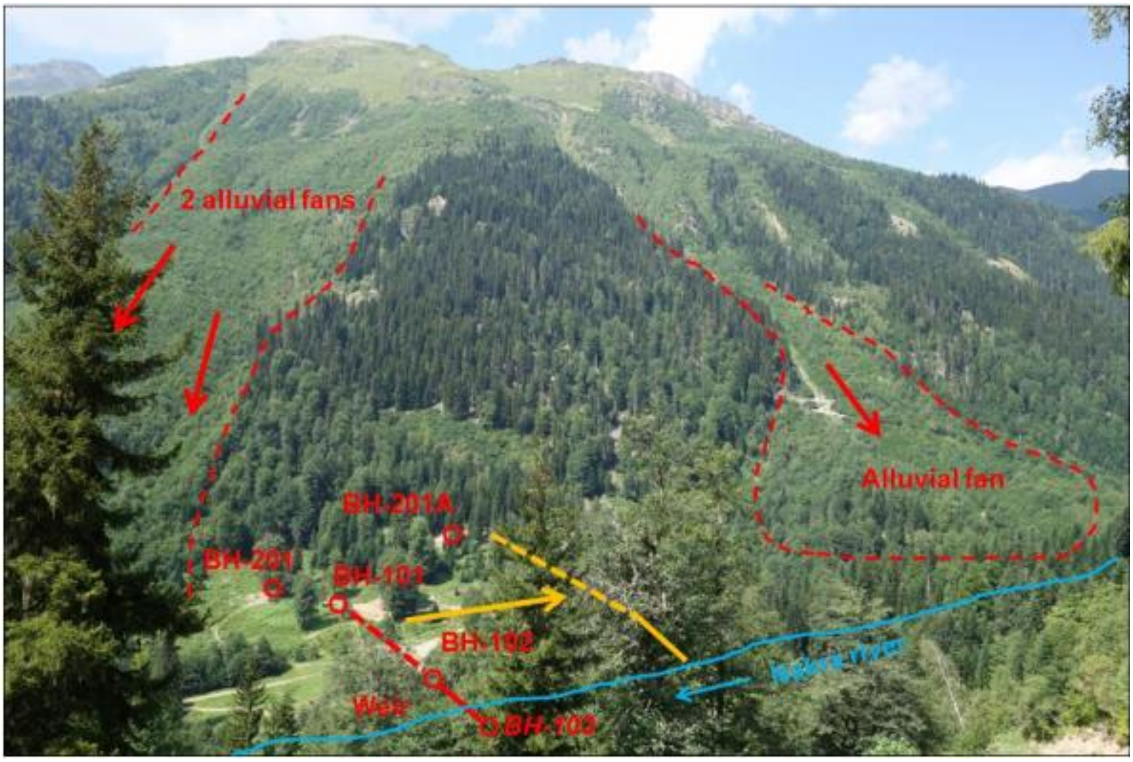


Figure 14 – Location of Nakra weir and transfer tunnel inlet portal

4.1.3 Nakra camp and technical installation

The Nakra camp and the technical installation are located a few hundred meters downstream from the Nakra intake, on the right bank. The layout of the camp and technical installation is illustrated in the sketch provide in Figure 15

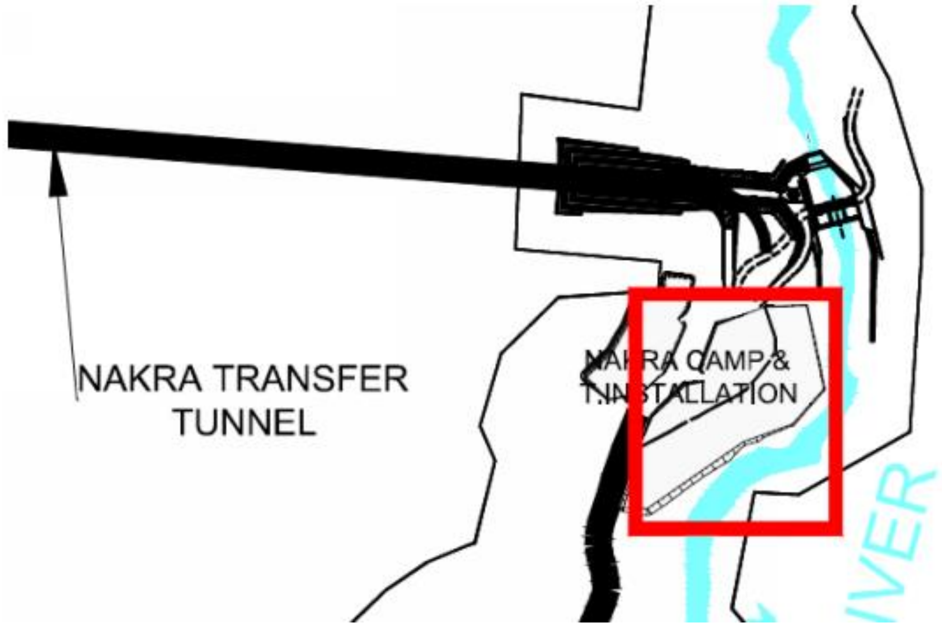


Figure 15 – Sketch of the Nakra camp and technical installation layout

The slope above the site are moderately steep and occupied by a vegetation of relatively young trees, though this is thought to be by the result of logging activities, rather than avalanches and landslide activities. However, avalanche and rockfall hazards will be assessed prior the start of the works in order to assess possibly localized problems and design protection measures, as captured by [SAF 3] Detailed natural hazard risk assessment for all construction camps and technical installations to be completed before camps and installations constructed.

4.2 Risks to communities

This section describes the increased risk of flooding in the Nakra valley that is an indirect result of the Project. This issue is described in detail in Volume 5 – Hydrology, geomorphology and water quality impact assessment.

4.2.1 Description of the baseline situation

Immediately upstream of the Nakra village, on right bank of the Nakra, is located the Lekverari torrent – a tributary of the Nakra River. In 2011, at the beginning of August, a particularly heavy rain storm triggered a landslide in the gorge through which flows the Lekverari flows. The Lekverari was in flood at the time and consequently transported a large amount of sediment from the landslide downstream to the confluence with the Nakra River, and blocked the Nakra by creating a natural dam. Within a few minutes flooding had occurred upstream extending some 800 metres. The location of the river blockage and temporarily flooded area is illustrated in Figure 16 below. Within about 5 minutes of the flooding, the force of the water flowing in the Nakra River – which was in flood – burst the blockage and caused a large wave of water to descend the river, though without causing any flooding. The natural flow of the Nakra River then progressively flushed away much of the remaining sediment.

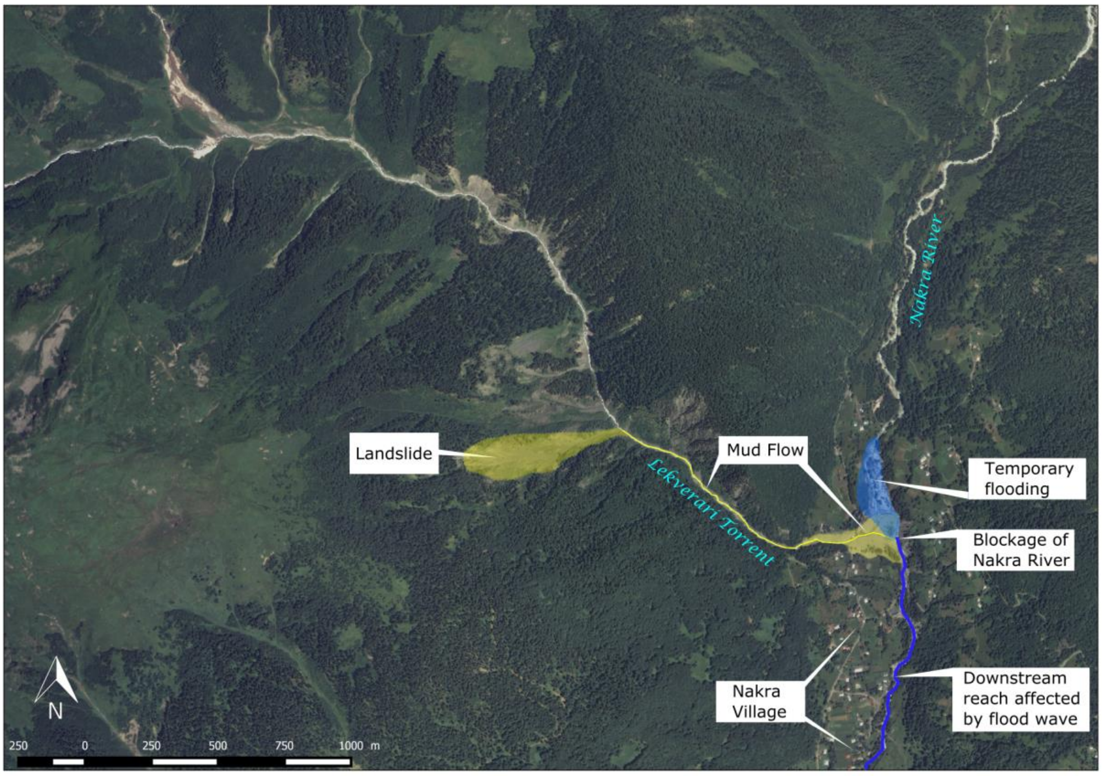
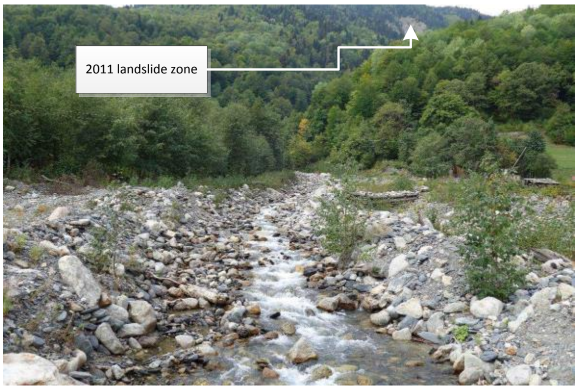
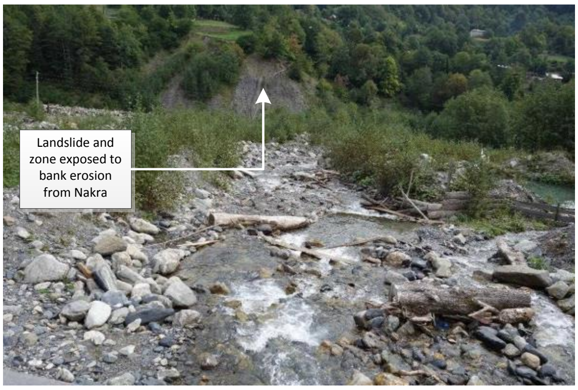


Figure 16 – Localisation of the Lekverari mudflow event, temporarily blocking the Nakra in 2011



Lekverari torrent
Photo taken from Nakra village.
2011 landslide visible in upstream gorge



Lekverari torrent at Nakra village – looking downstream to the confluence with Nakra

Lekverari gorge - zone exposed to landslide risk

Nakr River – at Nakra village – remains of solid material transported by Lekverari torrrent followin g landslide in 2011 – and which blocked the Nakra
Illustrates the depth of material that blocked the river

Lekverari torrent aluvial fan at confluence with Nakra River

Lekverari torrent aluvial fan at confluence with Nakra River

Photo Sheet 1– Geomorphology features at the Lekverari – Nakra confluence

4.2.2 Influence of the Project on flooding risk

The construction of the diversion weir and the diversion of the Nakra River flow to the Nenskra Reservoir will significantly reduce the flow and consequently the solid transport capacity of the river. However, a large amount of sediment will continue to make its way into the river downstream from the weir, transported by the Lekverari and Laknashura Rivers. Therefore, the reduced solid transport capacity of the Nakra River flow is not balanced by a reduced sediment input and there will be a tendency for sediment accumulation in the river. This impact is discussed in Volume 5 – Hydrology and water quality impact assessment.

Consequently, as a result of the Project without mitigation measures, sediment accumulation in the river could make the Nakra more vulnerable to blockage from mudflow events such as that which occurred in 2011.

The measures to mitigate the risk are described in detail in Volume 5 – Hydrology and water quality impact assessment. The Nakra weir will be equipped with two large gates and the Nakra transfer tunnel inlet will be equipped with a gate. During flood events, the transfer tunnel gate will be closed and the weir gates open to allow the natural Nakra flow rate to be re-instated to allow sediment transport function to be periodically maintained downstream from the weir. In addition, studies to determine the most technically feasible solution to manage sediment in the Nakra will be undertaken. These measures are referred to later in this report as:

- [SAF 26] Measures to manage sediment in the Nakra and reduce flooding risk linked to sediment accumulation.

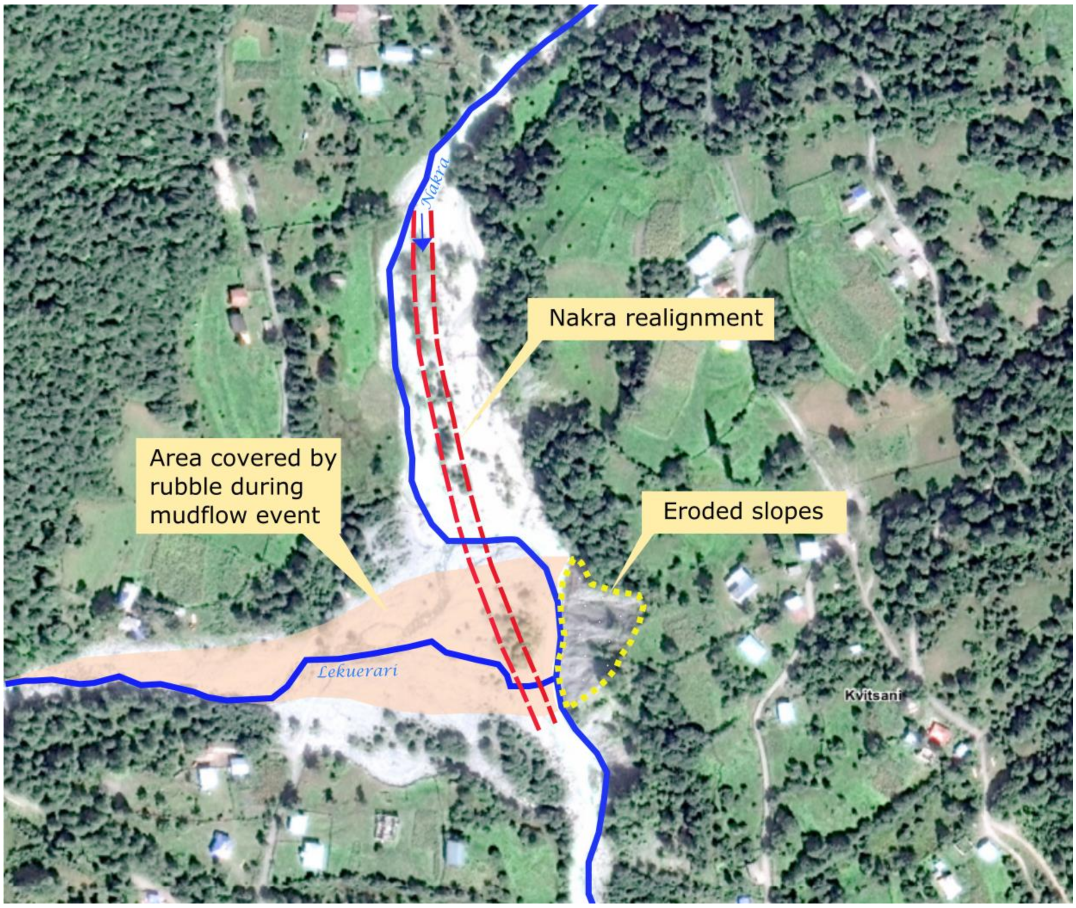


Figure 17 – Realignment of Nakra expected by people of Nakra village

4.2.3 Landslide events triggered by tunnelling operations

The Project has undertaken an evaluation of the vibrations induced by the excavation of the required tunnels. The evaluation has been carried out in view of establishing if there is a risk of slope instability that could cause landslide events affecting communities, and if the vibrations from the tunnelling could disturb communities. The evaluation has estimated vibration intensity at the source and the attenuation with distance. Calculations are based on the state-of-the-art literature and international technical recommendations.

The evaluation has been carried out for the Project tunnelling in general, and the approach and findings are provided in section 3.2.6 which addresses the risk in the Nenskra valley. The conclusion for the Nakra valley are the same, i.e. the typical level of vibration from a TBM and taking into consideration the geology of the project area, and characteristics of the tunnels to be excavated, the predicted vibrations at ground level are much lower than vibrations that could generate slope stability problems or disturb communities.

5 Emergency preparedness

This section presents the extremely unlikely sequence of events that if they were to occur could result in the failure of the Nenskra dam or the coffer dam, a preliminary estimate of the consequences of such events and basic principles for the Emergency Preparedness Plan (EPP) that will be developed and implemented. The preliminary EPP is provided as an annex to Vol. 8 ESMP.

5.1 Dam failure modes and safeguards

An overview of dam failure modes is provided in this section. A detailed dam failure risk assessment in alignment with ICOLD methodologies will be undertaken as the project moves forward. The risk assessment will take into account potential linkage of initiating events, for example the case where a debris flow may be triggered by extreme rainfall and so concurrent with a PMF. This commitment is referred to later in this report as:

[SAF 27] Dam failure risk assessment in alignment with ICOLD methodologies.

5.1.1 Dam-reservoir in operation

The possible (but extremely unlikely) unwanted events that could lead to dam failure when then dam is in operation are (i) dam structure instability, and (ii) overtopping of the dam structure. The sequence of events that could lead to these unwanted events and ultimately dam failure is illustrated in the fault trees provided in Figure 18 and Figure 19. The different initiating events and the safeguard measures are described in Table 8 and Table 9.

5.1.2 During reservoir filling / early energy generation phase

Towards the end of the construction phase – when the dam structure construction is sufficiently advanced – the reservoir will be partially filled so that early energy generation can start. However, during this phase – which has a duration of approximately one year – the reservoir water level will not reach the spillway. The chain of unlikely events that could lead to a dam failure are the same as for the dam-reservoir in operation, however, the blockage of the spillway event is not applicable.

5.2 Coffer dam failure modes and safeguards

During the construction phase, the unlikely unwanted events that could lead to coffer dam failure are illustrated in the fault tree provided in Figure 20, and the initiating events and safeguard are described in Table 10 and Table 11.

The coffer dam is not considered as a large dam by ICOLD, as it has a height of only 10 metres.

Figure 18 – Fault tree for dam overtopping during operation

Table 8 – Dam overtopping during operation – initiating events and safeguards

<table>
<tr><td>Unwanted Event:</td><td colspan="2">Overtopping of the dam</td></tr>
<tr><td colspan="3">Description: Occurs when reservoir water reaches a level that is above the crest of the dam, and resulting in water flowing over the top of the dam. A rockfill dam will not withstand the hydraulic loads created by such a situation. The water flowing over the downstream slope of the dam will cause external erosion of the dam material causing a weakening of the dam structure. In dam risk analysis, good practice is to assume that the dam will fail if overtopping occurs.</td></tr>
<tr><td>Initiating Event 1: Extreme flood event with peak flood flows that are greater than the spillway capacity.</td><td>Initiating Event 2: Reservoir outlets blocked or unavailable (Bottom Outlet (BO), headrace tunnel portal, and spillway) at the time that a flood event occurs [a] or that inflow is greater than turbine capacity when the reservoir is full.</td><td>Initiating Event 3: Creation of a large impulse wave in the reservoir.</td></tr>
<tr><td>Description: Could occur if the spillway capacity has been underestimated during the design and an extreme flood event occurs.</td><td>Description: Blockage could be caused by: (i) debris flow, (ii) avalanche flow, or (iii) accumulation of floating debris (tree-trucks and possibly combined with accumulation of snow and ice).</td><td>Description: Impulse wave could be caused by: (i) a huge avalanche, (ii) large landslide, or (iii) high sudden inflow from the breach of a natural dam created by a landslide in the upper catchment.</td></tr>
<tr><td>Safeguards:

• [SAF 6] Hydrological studies, definition of PMF and flood control designed to evacuate PMF.
• [SAF 7] Climate changes taken into account in determining PMF – and design of flood control structures.</td><td>Safeguards:

• Modelling of potential avalanche and debris flow events carried out in order to position spillway, BO and headrace tunnel portal away from areas potentially affected by avalanche and debris flow.
• Protection measures included in the design to protect structures (spillway, BO, headrace tunnel portals) from avalanche and debris flow events and to protect workers during construction work
• Stability of slope above spillway, BO and headrace tunnel portal monitored.
• Monitoring of snow accumulation to evaluate risk of major avalanche impacting the spillway, headrace tunnel portal and BO
• Log boom or similar to prevent floating debris blocking the spillway
• Manual clearing in the event blockage of spillway, BO or headrace tunnel portal.
The above measures are referred to as:
• [SAF 28] Measures to mitigate blockage of spillway, bottom outlet and headrace tunnel portal.
If necessary the BO can be used to lower reservoir water level and evacuate the flood flow:
• [SAF 29] Bottom outlet designed with capacity of 200 m³/s.</td><td>Safeguards:

• [SAF 13] Risk assessment with regard to avalanche generated impulse waves, dam overtopping and eventual changes in Project design, if necessary

• Monitoring of snow accumulation to evaluate risk of major avalanche impacting the reservoir.
• Procedures for lowering reservoir water level in the case of expected event that could cause a large impulse wave.
The above measures are referred to as:
• [SAF 30] Measures to mitigate risk of generation of an impulse wave in the reservoir.</td></tr>
<tr><td colspan="3">[a] Debris flow events are linked with periods of extreme precipitation and could therefore occur at the same time as an extreme flood event. Extreme floods are known to occur at the end of the summer and autumn, and this is the period when the reservoir will probably be at its maximum operating level. Avalanche risk is expected to be present during the winter months and early spring. In November the reservoir water level will be at maximum operating level and progressively during the winter the level will be lowered and reach its minimum operating level in March.</td></tr>
</table>

Figure 19 – Fault tree for dam failure during operation

Table 9 – Dam failure during operation – initiating events and safeguards

Unwanted Event:	**Dam structure instability and possibly leading to failure**		
Description: Degraded dam stability could result in a reduction in the capacity of the dam to withstand hydraulic loads and could lead to the failure of the dam if the phenomenon is not detected and corrective action not taken. The overtopping is a cause of dam instability and is described in Table 8 on the previous page.			
Initiating Event 1: Internal erosion	**Initiating Event 2:** External erosion of the dam material	**Initiating Event 3:** Foundation erosion causing reservoir water to pass under the dam structure	**Initiating Event 4:** Seismic loading
Description: Rupture or damage to the protective face could cause increased ingress of water into the core material causing internal erosion and weakening the structure. The damage to the protective face could be caused by (i) settling of rockfill construction material, (ii) from avalanche or debris flow, (iii) floating tree trucks, or (iv) from a seismic event.	**Description:** Could occur in the event of overtopping (see Table 8) or as a result of avalanche or debris flow events impacting the dam structure. The external erosion can cause a weakening of the dam structure.	**Description:** The geology underlying the dam structure comprises a layer of pervious alluvial deposits overlaying the solid stable and impervious layer of rock. In the absence of the safeguards the passage of water through the layer of alluvial deposit under the dam could cause erosion, and cause a breach to be formed under the dam.	**Description:** In the event of an earthquake creating ground acceleration at the dam site that are greater than that of dam design criteria there will a weakening of the dam structure.
Safeguards: • Dam asphaltic face designed to withstand necessary hydraulic and seismic loads. • Strict supervision of dam construction to ensure that settling of dam core materials does not occur. • Dam equipped with instrumentation with monitoring systems to monitor changes in stability. • Dam structure subject to regular inspections during operation. The above measures are referred to as: • [SAF 31] Measures to mitigate internal erosion of the dam structure.	**Safeguards**: • Modelling of avalanche and debris flow events carried out and used to design protective structures, and/or revise dam design if necessary. • Monitoring of snow accumulation to evaluate risk of major avalanche impacting the dam structure. • Inspections of the dam structure undertaken after an avalanche or debris flow. • If necessary, reservoir water level lowered using the bottom outlet and remediation works carried out. The above measures are referred to as: • [SAF 32] Measures to mitigate external erosion of the dam structure from avalanche and debris flow events. The measures to mitigate dam overtopping are listed in (see Table 8).	**Safeguards:** • Cut-off wall below the base of the dam. Extends through the entire depth of the alluvial deposits and into the Fluvio-glacial deposits of lower permeability. • Grouting (injection of cement) to reduce permeability of certain zones of alluvial deposits beneath the dam. • Groundwater monitoring wells installed and used to detect signs of the passage of water. The above measures are referred to as: • [SAF 33] Measures to mitigate internal erosion of the dam foundation alluvial strata.	**Safeguards:** • [SAF 4] Earthquake hazard assessment, definition and design of dam structure to withstand Maximum Credible Earthquake • Geotechnical studies to confirm that dam foundation is not susceptible to liquefaction. • Physical and numerical modelling used to validate that the dam can withstand the maximum credible earthquake. • Dam equipped with instrumentation with monitoring systems to monitor changes in stability. • Inspections of the dam structure undertaken after seismic event. • If necessary, reservoir water level lowered using the bottom outlet and remediation works carried out. The above measures are referred to as: • [SAF 34] Measures to mitigate risk of dam instability resulting from seismic activity

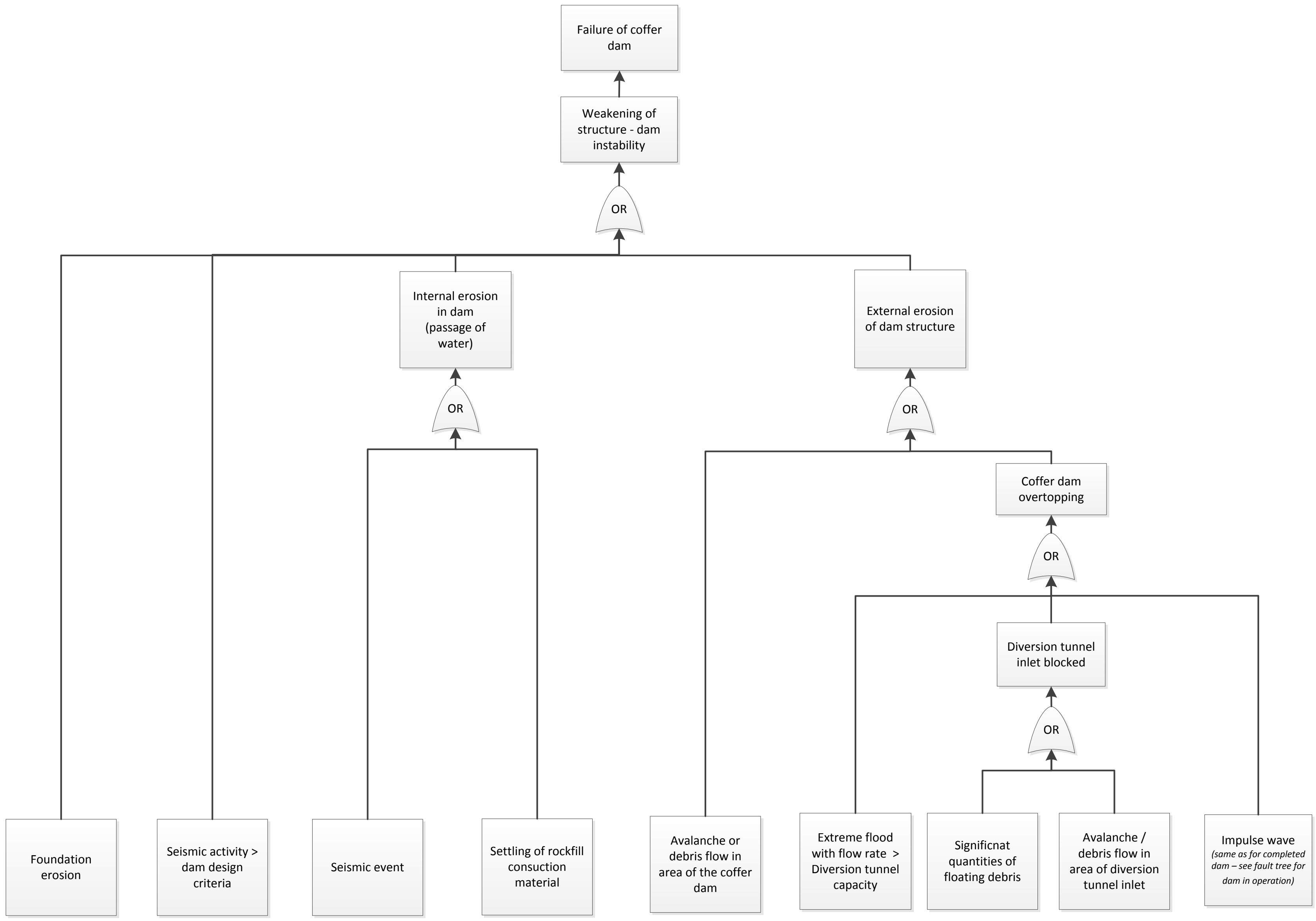


Figure 20 – Fault tree for failure of coffer dam

Table 10 – Coffer dam overtopping – initiating events and safeguards

<table>
<tr><td>Unwanted Event:</td><td colspan="2">Coffer dam overtopping</td></tr>
<tr><td colspan="3">Description: Overtopping of the coffer dam is a situation where the reservoir water reaches a level that is above the crest of the coffer dam, and resulting in water flowing over the top of it. A rockfill coffer dam will not withstand the hydraulic loads created by such a situation. The water flowing over the downstream slope of the coffer dam will cause external erosion of the coffer dam material causing a weakening of the coffer dam structure. In coffer dam risk analysis, good practice is to assume that the coffer dam will fail if overtopping occurs.</td></tr>
<tr><td>Initiating event 1: Extreme flood event with peak flood flows that are greater than the diversion tunnel capacity</td><td>Initiating event 2: Diversion tunnel blocked at the time that a flood event occurs [a]</td><td>Initiating event 3: Creation of a large impulse wave on the reservoir upstream coffer dam</td></tr>
<tr><td>Description: This situation could occur if the diversion tunnel capacity regarding maximum allowed water level upstream the cofferdam has been underestimated during the design and an extreme flood event occurs.</td><td>Description: Could be caused for example by debris flow, avalanches flow or sediment. Accumulation of floating debris (tree-trucks and possibly combined with accumulation of snow and ice), as well as sediment and debris could also block the entrance of the diversion tunnel.</td><td>Description: Description: Impulse wave could be caused by: (i) a huge avalanche, (ii) large landslide, or (iii) high sudden in flow from the breach of a natural dam created by a landslide in the upper catchment.</td></tr>
<tr><td>Safeguards:
• [SAF 35] Coffer dam diversion tunnel designed with the capacity to evacuate a flood with a return period of 25 years during.
• [SAF 36] Risk assessment used to confirm flood evacuation capacity of the coffer dam diversion tunnel is commensurate with risk and design modified if necessary.</td><td>Safeguards:
• Modelling of avalanche and debris flow events carried out in order to evaluate the need for and design of protective structures for the protection of the diversion tunnel during construction.
• Monitoring of snow accumulation to evaluate risk of major avalanche impacting the diversion tunnel during construction.
The above measures are referred to as:
• [SAF 37] Measures to mitigate risk of diversion tunnel blockage during construction.</td><td>Safeguards:
See Table 8 initiating event 3</td></tr>
<tr><td colspan="3">[a] Debris flow events are linked with periods of extreme precipitation and could therefore occur at the same time as an extreme flood event. Extreme floods are known to occur at the end of the summer and autumn, and this is the period when the reservoir will probably be at its maximum operating level. Avalanche risk is expected to be present during the winter months and early spring. In November, the reservoir water level will be at maximum operating level and progressively during the winter the level will be lowered and reach its minimum operating level in March.</td></tr>
</table>

Table 11 – Coffer dam failure by degraded structure stability – initiating events and safeguards

<table>
<tr><td>Unwanted Event:</td><td colspan="2">Degraded coffer dam stability</td></tr>
<tr><td colspan="3">Description: Degraded coffer dam stability could result in a reduction in the capacity of the coffer dam to withstand hydraulic loads and could lead to the failure of the coffer dam if the phenomenon is not detected and corrective action not taken.</td></tr>
<tr><td>Cause 1: Internal erosion of the coffer dam material</td><td>Cause 2: Foundation erosion causing water to pass under the coffer dam structure</td><td>Cause 3: Seismic loading</td></tr>
<tr><td>Description: Settling of rockfill construction material or movement of material caused seismic event could cause increase of seepage into the structure’s material, causing internal erosion – and if not detected, weakening the structure.</td><td>Description: The geology underlying the coffer dam structure comprises a layer of pervious alluvial deposits overlaying the solid stable and impervious layer of rock. In the absence of the safeguards the passage of water through the layer of alluvial deposit under the dam could cause erosion, and cause a breach to be formed under the dam.</td><td>Description: In the event of an earthquake creating ground acceleration at the coffer dam site that are greater than coffer dam design criteria there will a weakening of the coffer dam structure and possibly rupture of the coffer dam.</td></tr>
<tr><td>Safeguards:
• Coffer dam construction follows strict execution method and is supervised.
• Stability of the cofferdam is monitored.
• Coffer dam is subject to regular inspections and monitoring of seepage water rates.
• Corrective action taken if inspections and monitoring detect signs of internal erosion in the coffer dam structure.
The above measures are referred to as:
• [SAF 38] Measures to mitigate risk of internal erosion of the coffer dam.</td><td>Safeguards:
• Diaphragm wall in the alluvial deposits at the centre of the coffer dam structure and to a depth of 25 m below the base of the coffer dam.
• Necessity for coffer dam groundwater monitoring shall be assessed, and installed if needed, and monitoring system shall be installed.
• Corrective action will be taken if groundwater monitoring detects signs of internal erosion in the alluvial deposits underlying the coffer dam.
The above measures are referred to as:
• [SAF 39] Measures to mitigate risk of coffer dam foundation erosion.</td><td>Safeguards:
• Coffer dam designed to withstand an earthquake with a return-period of the 145 years.
• A simplified 2D static and pseudo-static analysis carried out to verify that the coffer dam design will indeed withstand the 145-year return period earthquake.
• Stability of the cofferdam is monitored.
• Inspections of the coffer dam undertaken after a seismic event.
The above measures are referred to as:
• [SAF 40] Measures to mitigate risk of coffer dam instability as a result of seismic loading</td></tr>
</table>

5.3 Consequences of dam failure

This section presents the results of a preliminary indicative dam break model that has been used to estimate the consequences of dam failure. Once studies designed to more accurately determine modelling input data have been performed a detailed dam break simulation modelling will be undertaken to determine the extent of downstream flooding for emergency situations, included in the Emergency Preparedness Plan (see section 5.4) and communicated to local communities for emergency planning purposes. The flood modelling is a requirement of Georgian law, Good International Practice and is a requirement of the Lenders' policies.

The undertaking of these studies and undertaking of the formal modelling is captured in commitment [SAF 21] Flood study downstream of the dam for the case of dam failure, full and partial bottom outlet opening, natural flood events and include early warning mechanism. See page 25.

The impact on the Khudoni dam-reservoir is provided in Vol. 10 – Cumulative Impact Assessment.

5.3.1 Nenskra valley

Several dam break models are available to estimate the dam breach hydrograph. The main characteristics of the outflow are usually based on semi empirical methods. As the objective of the present study is to estimate the upper limit of the flood caused by the dam break the *Centre technique du Génie Rural des Eaux de des Forêts*[6] (CTGREF) method is considered as the most suitable and has been chosen for the computation. This tool has been developed by the Swiss federal Office of Energy in 2001 and 2006. This model has been selected as it is a fairly recently updated model and developed by a governmental office in Switzerland, which is a country with predominant mountainous terrain similar to that in Georgia and a highly developed hydropower sector.

Depending on the empirical formula used, the breach width can vary between 187 metres (Froehlich, 2008) to 374 metres (Von Thun and Gilette, 1990). The peak discharge is predicted to be between 67,724 m^3/s (Froehlich, 1995b) and 491,000 m^3/s (instant partial break). The corrected instant flow given by the CTGREF method is equal to 284,810 m^3/s.

The intensity value, defined as the product of the flood speed by the maximum depth, is a good indicator of the impact of the flood in a given area. This value depends on the topography (cross section, slope of the valley) and the ground characteristics (Stickler coefficient). As shown in Table 12, the intensity logically tends to decrease when the wave goes in the downstream direction. However, in the Enguri valley and due to its relative narrowness, the intensity is a slightly higher than expected.

Table 12 : Estimated characteristics of the dam break wave for the Nenskra dam

Area	Q_{max} [m^3/s]	Intensity [m^2/s]	Velocity [m/s]	Max. depth [m]
Vicinity downstream	279,000	1,065	34	31
Chuberi	202,000	380	25	15
Nenskra Powerhouse	179,000	407	20	20
Tail of Enguri reservoir	117,000	529	15	35

[6] Technical Center for Rural Engineering, Water and Forests

The water depth at Chuberi will be 15 metres and this will overtop the banks of the Nenskra and cause flooding of most of the Nenskra valley. The communities at Tita, Chuberi and Khaishi will be catastrophically impacted.

5.3.2 Enguri dam

At the upper reaches of the Enguri reservoir, the peak flow of the dam break wave is estimated to reach a maximum of 117,000 m^3/s, which is less than half the peak flow estimated at the breach. The attenuation caused by the Enguri reservoir is computed considering a free overflow at the Enguri dam crest and assuming that the Enguri reservoir will be at maximum operating level at that time. As shown on Figure 21, an overflow with a maximum of about 12 metres could be expected over the dam crest during a couple of hours.

In the case that the Enguri reservoir water level is below the maximum operating level at the time of the Nenskra dam rupture, the depth of Enguri dam overflow will be less than 12 metres. If the Enguri reservoir is at minimum operating level for the scenario of a Nenskra dam failure, it should be able to receive the water released from the Nenskra reservoir without overtopping. The Nenskra reservoir has a volume of 176 million cubic metres and the live storage volume of the Enguri reservoir is volume of 676 million cubic metres.

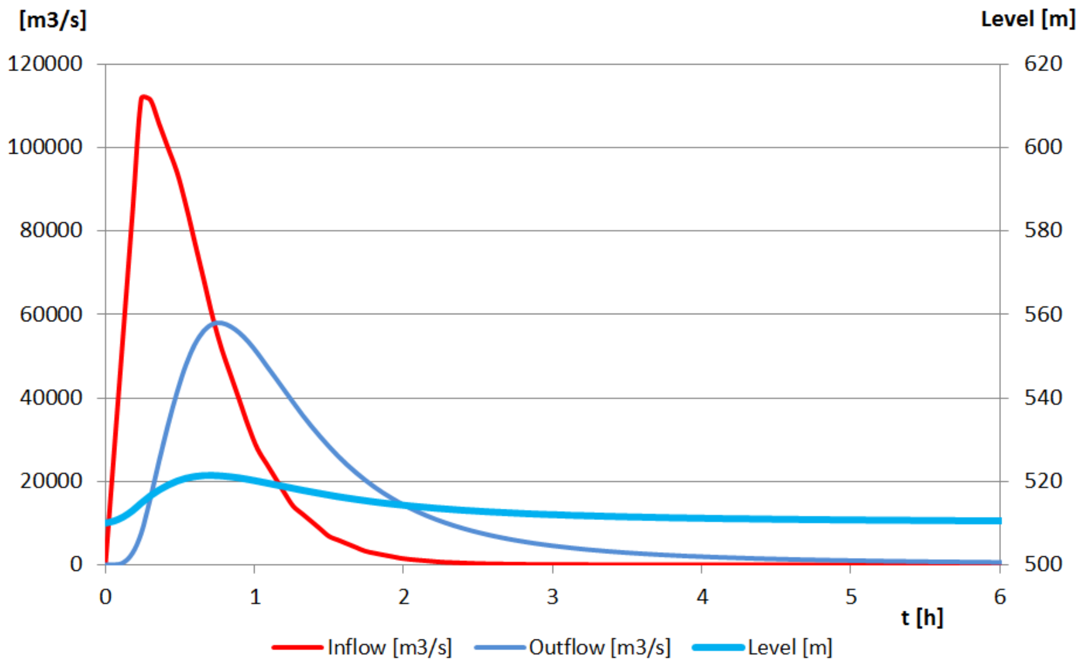


Figure 21 – Attenuation of the Enguri reservoir and estimated overflow

Due to the robustness of the Enguri dam as a concrete double curvature arch dam, it can be assumed, in a first simplified approach, that the risk of the Enguri dam failure due to a breach of the Nenskra dam is low. However, the capability of the dam to resist overtopping is not solely dependent on the type of dam and the depth of water above the crest, but also the stability of the base of the dam and the capacity of the foundations to resist the force of the water descending on the downstream side of the dam. It should therefore be considered that the Enguri dam would probably not fail, but that this should be confirmed by the results of the more detailed Nenskra dam break modelling and the studies by Georgian State Electrosystem (GSE) who manage the cascade of hydropower schemes including Enguri.

In association with the flood studies captured in commitment [SAF 21] Flood study downstream of the dam for the case of dam failure, full and partial bottom outlet opening, natural flood events and include early warning mechanism. (See page 25). The Project will also assess the risk of the rupture of the Enguri dam and the consequences of the resulting flood. The selected flood modelling approach will take into account the difficulties of obtaining detailed topographic data for the Enguri River downstream from the Enguri dam which is sensitivity from a geopolitical perspective, as the river represents the boundary with the breakaway region of Abkhazia and is considered by Georgia as an occupied territory. This commitment is referred to later in this report as:

- [SAF 41] Assessment of the risk of the failure of the Enguri dam as a result of the failure of the Nenskra dam using an ICOLD method and if necessary estimation of the consequences using flood modelling.

5.4 Emergency preparedness plan

The Nenskra dam has been designed and will be constructed and operated so that the dam failure is extremely unlikely. Given the consequences of such an unlikely event, in compliance with good industry practices, the Project is developing a comprehensive and consistent EPP to protect lives and reduce property damage in case of dam failure or operational incident. A preliminary EPP is provided as an annex to Vol. 8 ESMP and this will be updated in H1 2018 with the inclusion of flood modelling and will be available H1 2018, prior to the first river closure. The Project Company will engage with communities with regard to the EPP during Q4 2017 / Q1 2018.

The EPP identifies and determines the Project Company responses to emergency situations for the Nenskra dam, defined as follows: (i) dam failure; (ii) sudden discharge from the dam; (iii) circumstances that potentially increase the likelihood of a dam failure or sudden discharge occurring.

The EPP includes 2 plans: an internal plan (describing how the operator manages the risk of major dam failure) and an external plan (for the civil security authorities, including flood maps for different scenarios). The main components of the plan include the following:

- The engagement of all entities, jurisdictions, and individuals that should be consulted in the preparation of the Nenskra EPP.
- A detailed Dam Failure Analysis to develop dam failure hydrograph and to estimate routing dam break flows downstream and the preparation of inundation maps. This will also include the case of the coffer dam failure.
- The identification of response actions to be taken by dam operator in response to potential emergencies or significant changes in releases or outflows from dams during floods.
- Early Warning Systems, communication systems, both internal (between persons at the dam) and external (between dam personnel and outside entities or persons) to be activated in case of dam failure hazard
- Responsibilities, Notification flowcharts and contact information.
- Testing of Early Warning Systems and Exercises.
- As and if required by the local emergency management authorities, develop evacuation and shelter-in-place training materials for people in the Nenskra valley living immediately downstream of the dam and who would be inundated within a short time frame.
- Emergency Event Reporting.

These safeguard measures are referred to later in this report as:

- [SAF 42] Preparation of an Emergency Preparedness Plan prior to the first river closure – during the construction phase.
- [SAF 43] Design and installation of Early Warning Systems, and training of JSCNH staff.
- [SAF 44] Annual meeting with civil security services (authorities, civil security, elected representatives of the population) on day-to-day risks associated with the scheme operation and organisation of emergency situation exercises.

As a complement, management of exposure of users of the reservoir bypass cattle track to natural hazards such as debris flow, avalanche, rock fall (see section 3.2.5) will be addressed through the performance of a cattle track natural hazard risk assessment. The necessary mitigation measures will be designed and put in place by JSCNH prior to the moment the cattle track is brought into service. Risks and mitigations related to the use of the cattle track will be communicated to local communities during the annual EPP meetings with local community representatives. Risk mitigation measures will also form part of the handover to the municipality if it takes ownership.

6 Synthesis of safeguards

This section comprises a synthesis of the natural hazard and dam safety issues that are discussed in this report. The issues and corresponding safeguard measures that are marked [SAF] in this report are summarised in Table 13 overleaf. The [SAF] measures are not necessarily listed in the sequential order of their number.

Some of the measures are also proposed in other Supplementary E&S studies. For the sake of tracking and consistency, the summary table next page identifies which document addresses the safeguard described made in the present report.

Table 13 : Synthesis of natural hazard and dam safety issues and corresponding safeguards

Theme	Safeguard	Purpose of safeguard
Characterisation of natural hazards		
Extreme flood event	• [SAF 6] Hydrological studies, definition of PMF and flood control designed to evacuate PMF. • [SAF 7] Climate changes taken into account in determining PMF – and design of flood control structures.	Size reservoir flood control structures for PMF in order to prevent dam overtopping
Seismicity	• [SAF 4] Earthquake hazard assessment, definition and design of dam structure to withstand Maximum Credible Earthquake • [SAF 5] Adoption of seismic design criteria for buildings and facilities at the dam site, operator's village and powerhouse that are in alignment with Georgian seismic constriction codes and standards and Good International Practice.	Design dam structure to withstand MCE in order to prevent dam instability and failure Design buildings and facilities to withstand possible seismic events
Reservoir Triggered Seismicity	• [SAF 22] RTS assessment. • [SAF 23] Geological mapping of the faults near the dam site. • [SAF 24] Reservoir filling at less than 12 meters per week increase in depth • [SAF 25] Monitoring of seismic activities and slowing/stopping of filling if increased seismic activity is detected.	Prevent RTS with consequences on local communities
Glacial lake outburst flood	• [SAF 14] Natural hazard risk assessment – evaluation of GLOF risks.	Evaluation risk of GLOF impacting project components
Natural hazard risks for project assets and personnel	• [SAF 1] Natural hazard risk assessment.	Establish risk to project structures and personnel
Protection of structures and personnel		
Protection of structures (but not causing a knock-on effect on dam safety)	• [SAF 8] Nakra transfer tunnel outlet portal structure protected from potential rockfall • [SAF 16] Penstock worksite and construction workers are protected from potential rockfall. The protection measures are included in the design and installed at the start of the construction. • [SAF 17] Study to confirm debris flow risk at the powerhouse and if necessary define protection to be included in the design and built to protect the powerhouse, construction site and construction workers.	Protection of structures

Theme	Safeguard	Purpose of safeguard
Protection of worksites and construction workers against natural hazards	• [SAF 3] Detailed natural hazard risk assessment for all construction camps and technical installations to be completed before camps and installations constructed. • [SAF 9] Nakra transfer tunnel outlet portal worksite and construction workers are protected from potential rockfall. The protection measures are included in the design and installed at the start of the construction. • [SAF 10] Dam site, bottom outlet, spillway and headrace portal worksites and construction workers are protected from potential avalanche/debris flow events. The protection measures are included in the design and installed at the start of the construction. • [SAF 11] Monitoring, early warning system and identification of safe areas of avalanche and debris flow risk at the dam site, bottom outlet, spillway and headrace portal worksite worksites during construction and operation. • [SAF 12] Construction emergency preparedness plan developed and will include procedures for stopping work at worksites if monitoring indicates a risk of avalanche or debris flow events. Plan will also include response procedures. • [SAF 15] Penstock structure protected from potential rockfall. The protection measures are included in the design and installed during construction. • [SAF 18] Natural hazard protection measures to be included in the design of temporary construction camps and technical facilities to protect assets and workers.	Protection of workers during construction
Protection of operations staff from natural hazards	• See measures listed for dam failure mode below	Protection of workers during operation
Dam failure modes		
General	• [SAF 27] Dam failure risk assessment in alignment with ICOLD methodologies.	Manage risk of potential dam failure
Dam overtopping	• [SAF 13] Risk assessment with regard to avalanche generated impulse waves, dam overtopping and eventual changes in Project design, if necessary • [SAF 28] Measures to mitigate blockage of spillway, bottom outlet and headrace tunnel portal. • [SAF 29] Bottom outlet designed with capacity of 200 m3/s. • [SAF 30] Measures to mitigate risk of generation of an impulse wave in the reservoir.	Prevent overtopping – which could lead to dam failure
Dam instability	• [SAF 31] Measures to mitigate internal erosion of the dam structure. • [SAF 32] Measures to mitigate external erosion of the dam structure from avalanche and debris flow events. • [SAF 33] Measures to mitigate internal erosion of the dam foundation alluvial strata. • [SAF 34] Measures to mitigate risk of dam instability resulting from seismic activity	Prevent dam instability – which could lead to dam failure
Coffer dam overtopping	• [SAF 35] Coffer dam diversion tunnel designed with the capacity to evacuate a flood with a return period of 25 years during. • [SAF 36] Risk assessment used to confirm flood evacuation capacity of the coffer dam diversion tunnel is commensurate with risk and design modified if necessary. • [SAF 37] Measures to mitigate risk of diversion tunnel blockage during construction.	Prevent coffer dam overtopping – which could lead to dam failure
Coffer dam instability	• [SAF 38] Measures to mitigate risk of internal erosion of the coffer dam. • [SAF 39] Measures to mitigate risk of coffer dam foundation erosion. • [SAF 40] Measures to mitigate risk of coffer dam instability as a result of seismic loading	Prevent coffer dam instability – which could lead to dam failure

Theme	Safeguard	Purpose of safeguard
Emergency planning		
Consequences of dam failure of people and assets	• [SAF 42] Preparation of an Emergency Preparedness Plan prior to the first river closure – during the construction phase. • [SAF 43] Design and installation of Early Warning Systems, and training • [SAF 44] Annual meeting with civil security services (authorities, civil security, elected representatives of the population) on day-to-day risks associated with the scheme operation and organisation of emergency situation exercises.	Emergency preparedness planning
Consequences of dam on the Enguri dam	• [SAF 41] Assessment of the risk of the failure of the Enguri dam as a result of the failure of the Nenskra dam using an ICOLD method and if necessary estimation of the consequences using flood modelling.	Emergency preparedness planning
High unexpected flows in the Nenskra River		
Bottom outlet gate malfunction	• [SAF 19] Bottom outlet gate operation risk assessment in alignment with ICOLD methodologies. • [SAF 20] Measures to mitigate risk of bottom outlet gate malfunction. • [SAF 21] Flood study downstream of the dam for the case of dam failure, full and partial bottom outlet opening, natural flood events and include early warning mechanism.	Assess risk of gate malfunction and define measures to mitigate downstream health and safety risks for downstream communities
Natural hazard causing an impulse wave	• [SAF 30] Measures to mitigate risk of generation of an impulse wave in the reservoir.	Mitigate downstream health and safety risks for downstream communities
Risk of flooding in the Nakra River		
Risk of flooding in the Nakra due to increased sediment accumulation combined with the occasional blocking of the Nakra by landslide and mudflow events on the lateral tributaries	• [SAF 26] Measures to manage sediment in the Nakra and reduce flooding risk linked to sediment accumulation.	Reduce the risk of flood in the Nakra when a landslide and mudflow event occurs on lateral tributaries

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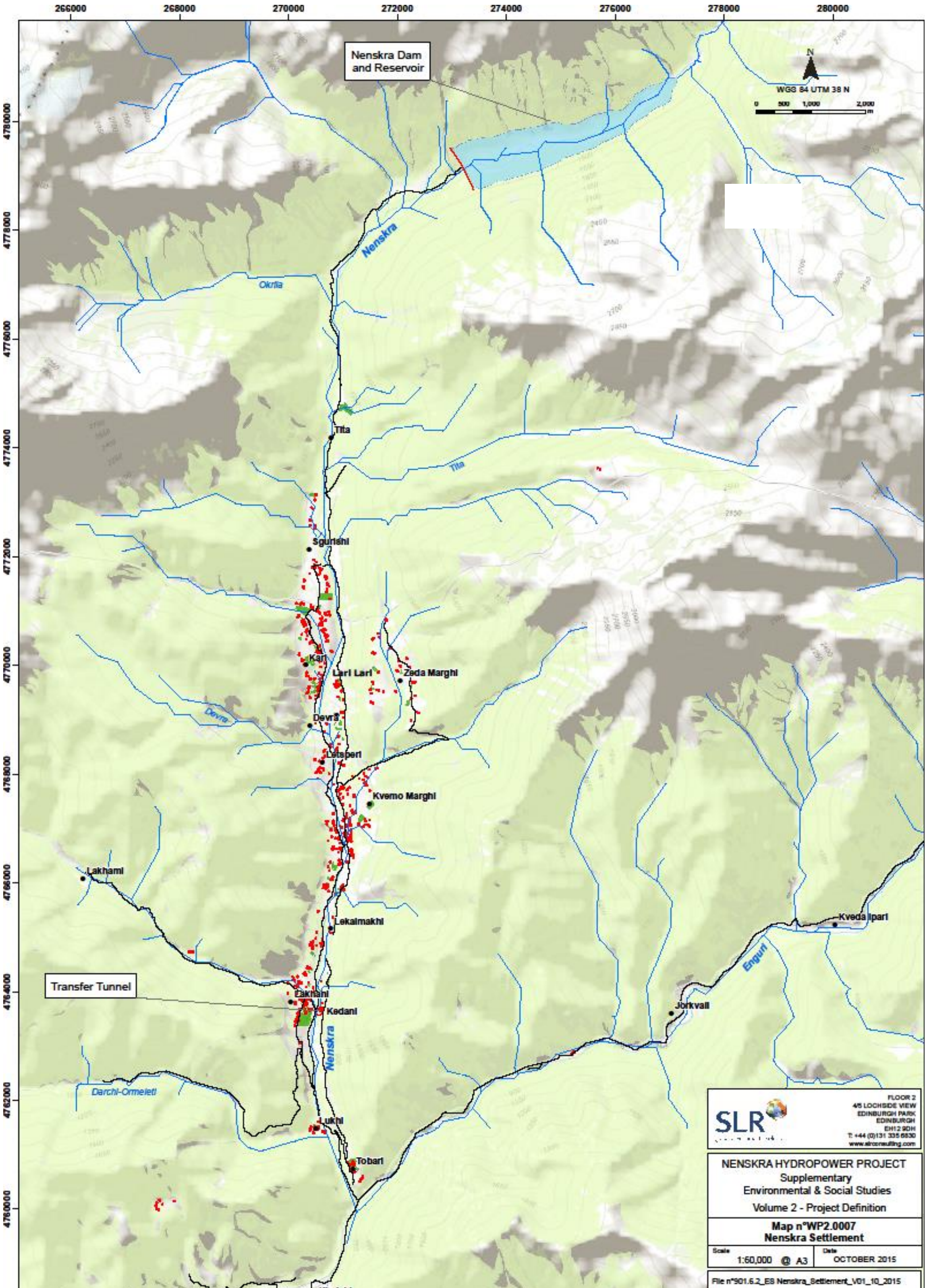
World Meteorological Organization, (1999) - *Comprehensive risk assessment for natural hazards*

Annex 2. Local communities location map



Annex 3. Methodology for estimating risk levels

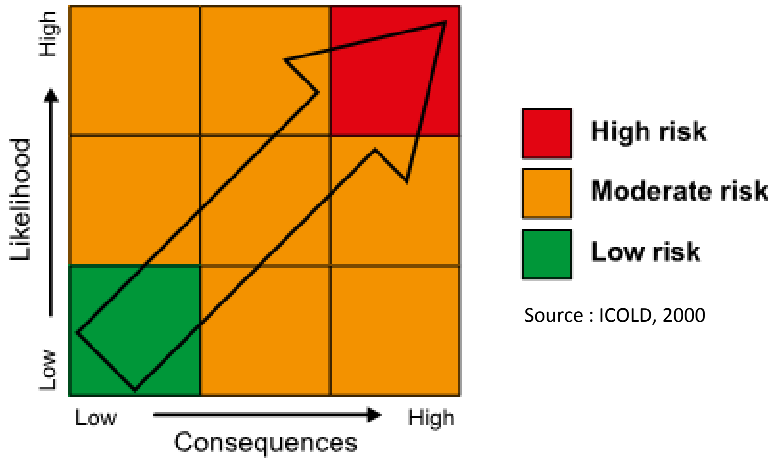
The Project's Natural Hazards Risk Assessment, which was conducted according to a structured risk assessment scheme has used the approach recommended by the International Commission on Large Dams for reservoir landslide assessment (ICOLD, 2000) – see figure below.

The risk is given as the combination of the two parameters of "likelihood of occurrence (L) and "expected consequences or damages (C). The resulting risk (R) is the product of the two parameters, as R = L x C.

As described in the ICOLD (2000) guidelines, the ranking of the likelihood and consequences are based in qualitative expert judgment, and the ranking is a relative ranking. Both components of risk (likelihood and consequences) are assessed in a three-level scale (low, moderate, high). Elements which allow for classification of the two components are:

- **Likelihood of occurrence:** Geological argumentation, such as the existence of former landslides or geomorphological evidence, or the presence of instability-favouring elements, such as destabilizing joint sets is used to qualitatively judge the possibility that a certain natural hazard process may develop in a certain area.
- **Consequences**: Possible damages to people, infrastructures and values, that may be directly at risk due to dam overtopping or damaging of the dam. An important decision help is the calculation of the height of the flood wave in the reservoir caused by a landslide collapse.

Judging both aspects results in a position in the 3 by 3 matrix with corresponding risk level (low, moderate, high), with the risk level increasing from bottom left to top right.



Qualitative risk matrix for reservoir risk assessment

Annex 4. Summary of seismic studies

Regional seismicity

The information provided in this subsection is taken from the Project's Earthquake Hazard Analysis.

The Project is situated at the intersection of the Eurasian, African and Arabian tectonic plates, within an active convergent zone of the Alpine-Himalayan orogenic system, as illustrated in Figure A4-1.

The Project lies in the western part of the Great Caucasus chain, as illustrated by the map provided in Figure A4-2. The map shows that the distribution of the seismicity in the Caucasus appears non-uniform, with earthquakes substantially less frequent in the western part of the chain than in the central and eastern parts. Consequently, the seismicity of the zone where the project is situated can be regarded as moderate, when compared to the seismicity of those parts of the chain located more to the east and southeast. This relative moderate seismicity of the western region, in which the project lies, is a long term feature.

Nevertheless, it is of note that a recent major seismic event occurred on April 29, 1991 – which was the Racha-Dzhava earthquake reaching a magnitude of Mw = 7.0 on the "*Moment Magnitude Scale (MMS)*" (see box below), which was the largest seismic event since the 18th century.

Seismic hazard analysis for the Project site

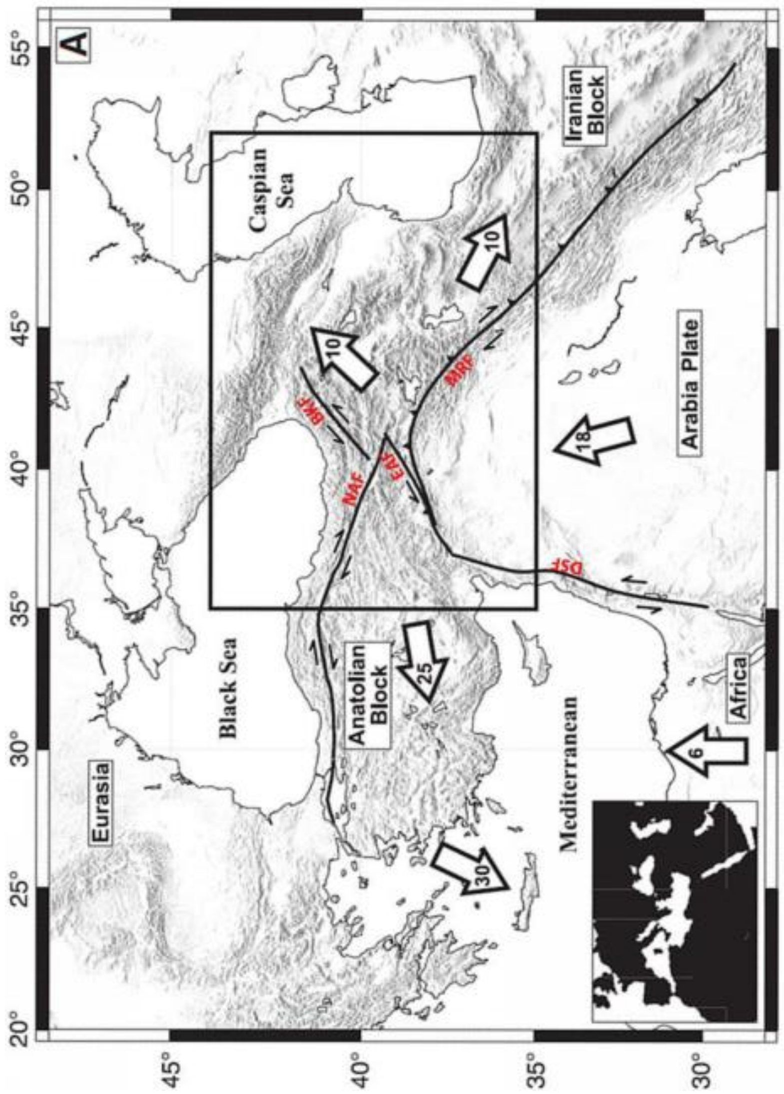
A probabilistic seismic hazard analysis has been undertaken by the Project and encompasses three main steps:

- Definition of seismic sources;
- Definition of attenuation relationship, and
- Calculation of ground motion parameters at the Project site.

The steps are described in the following paragraphs.

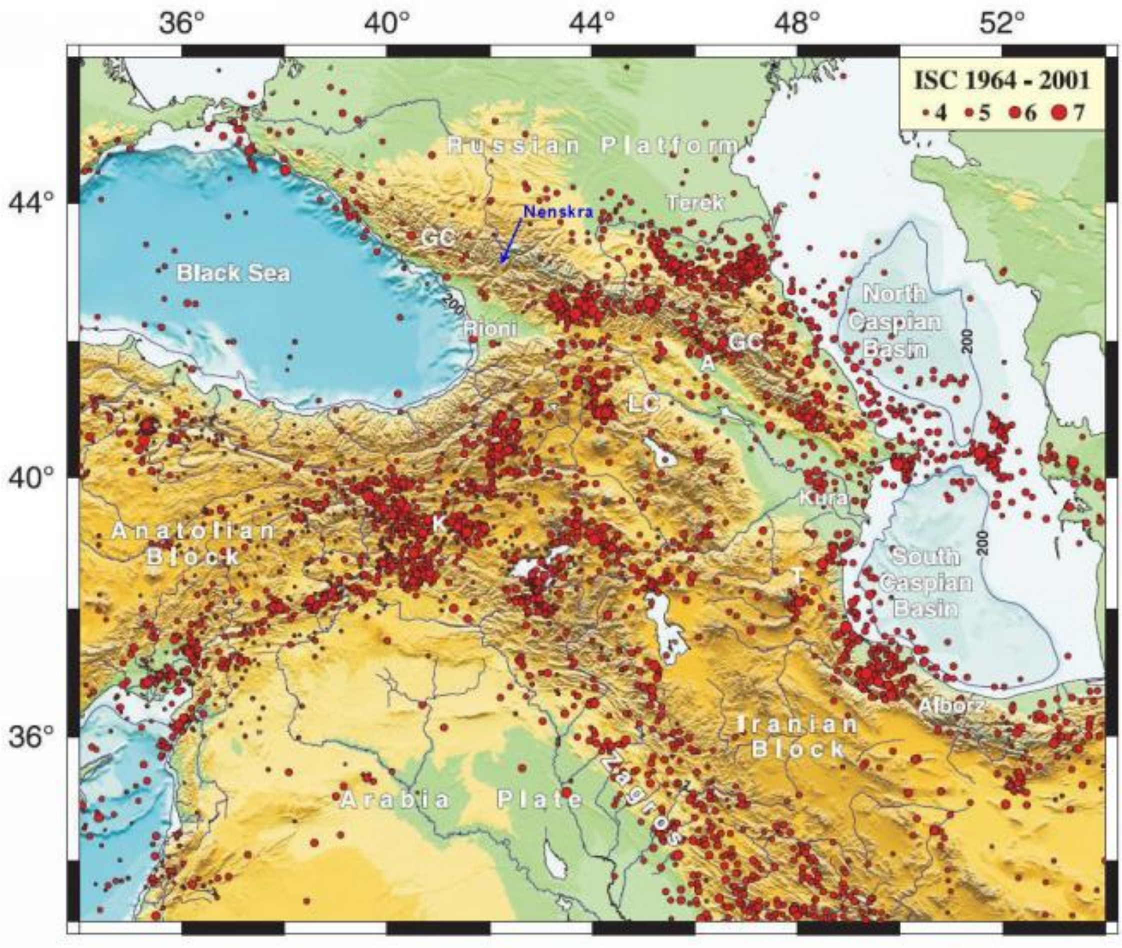
Definition of seismic sources

Tectonic earthquakes are generated by relative displacements along tectonic faults. A good knowledge of fault locations may allow a prediction of future earthquake locations when (i) the fault is recognized as tectonically active, and (ii) the seismic potential is proven by a record of well-located epicentres. However, data on active faults of the Western Caucasus are relatively scarce and the standard procedure for this type of situation is to assign earthquakes to so-called "*seismotectonic provinces*", which is an area with a unity of geological and seismic features. An earthquake is considered to be able to occur at any location within the province with the same likelihood. The Earthquake Hazard Analysis for the Nenskra Project has included analysis of the seismic history of the tectonics of the region in order to establish a single large areal source named the West Caucasian Source Zone (WCSZ) - illustrated in Figure A4-3 and which have been assembled into a seismotectonic source model of the type "*areal source with embedded faults*". The seismic activity of a large areal source is redistributed among the largest geological faults present in the same area, which, for this purpose, are all assumed to have seismogenic potential.



Source: Nenskra HPP Earthquake Hazard Assessment - originally in Tan & Taymaz, 2006

Figure A4-1: Relative plate motions in the eastern Mediterranean region



Source: Nenskra HPP Earthquake Hazard Assessment – originally in Tan & Taymaz, 2006

Figure A4-2: Seismicity of the Arabia-Eurasia collision zone

The Moment Magnitude Scale (MMS), denoted as Mw, is used by seismologists to measure the size of earthquakes in terms of the energy released. The magnitude is based on the seismic moment of the earthquake, which is equal to the rigidity of the Earth multiplied by the average amount of slip on the fault and the size of the area that slipped. The scale was developed in the 1970s to succeed the 1930s-era Richter magnitude scale. Even though the formulae are different, the new scale retains a similar continuum of magnitude values to that defined by the older one. Starting in January 2002 the MMS is officially the scale used by the United States Geological Survey to calculate and report magnitudes for all modern large earthquakes.

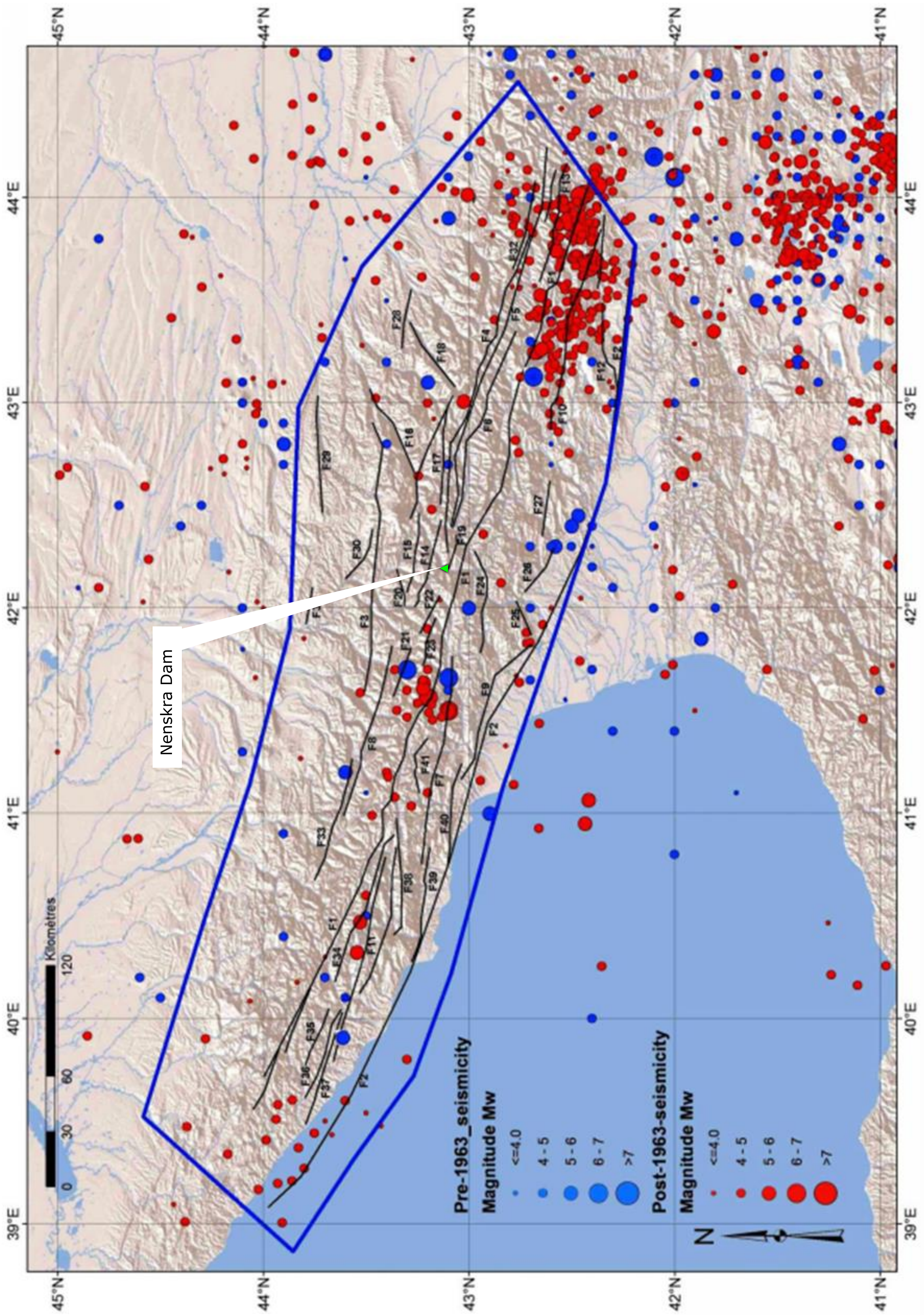


Figure A4-3: Epicentre map and West Caucasian Source Zone

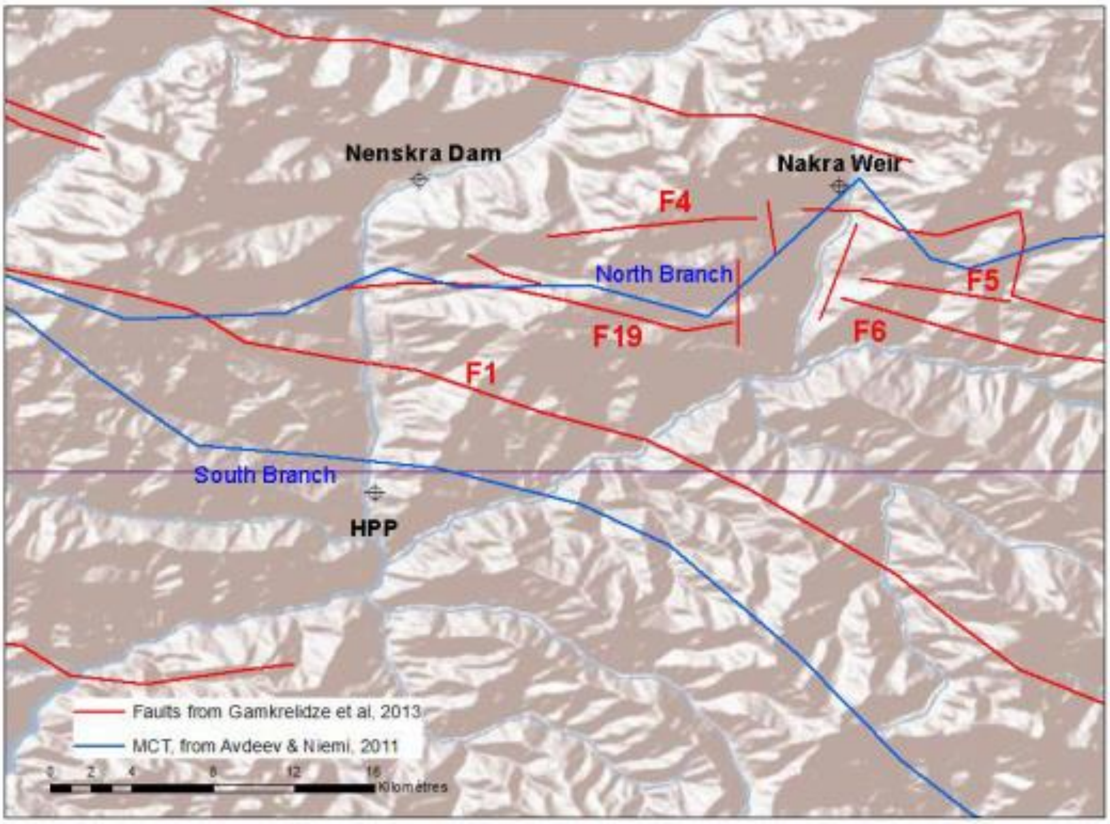


Figure A4-4: Main fault segments in the project region

The main faults near the project are illustrated on the map provided in Figure A4-4 and outlined as follows:

- Main Caucasian Thrust (MCT). The MCT is one of the main faults of the Caucasus, extending WNW-ESE along the whole length of the chain. The location of the MCT is not well expressed topographically in the project area and the Earthquake Hazard Analysis has made an estimation of the most likely position of the fault based on the work by Avdeev et al (2011) and from the recent New Tectonic Map of Georgia.
- Abkhaz-Lechkum Thrust. The thrust is part of the southernmost front of the Caucasus. The location and continuity of this thrust is controversial, as it is poorly expressed at the surface, or obliterated by recent deposits.

Other possible active faults are present in the region and the probabilistic approach for the estimating ground accelerations has taken into account 42 faults in total.

Definition of attenuation relationship

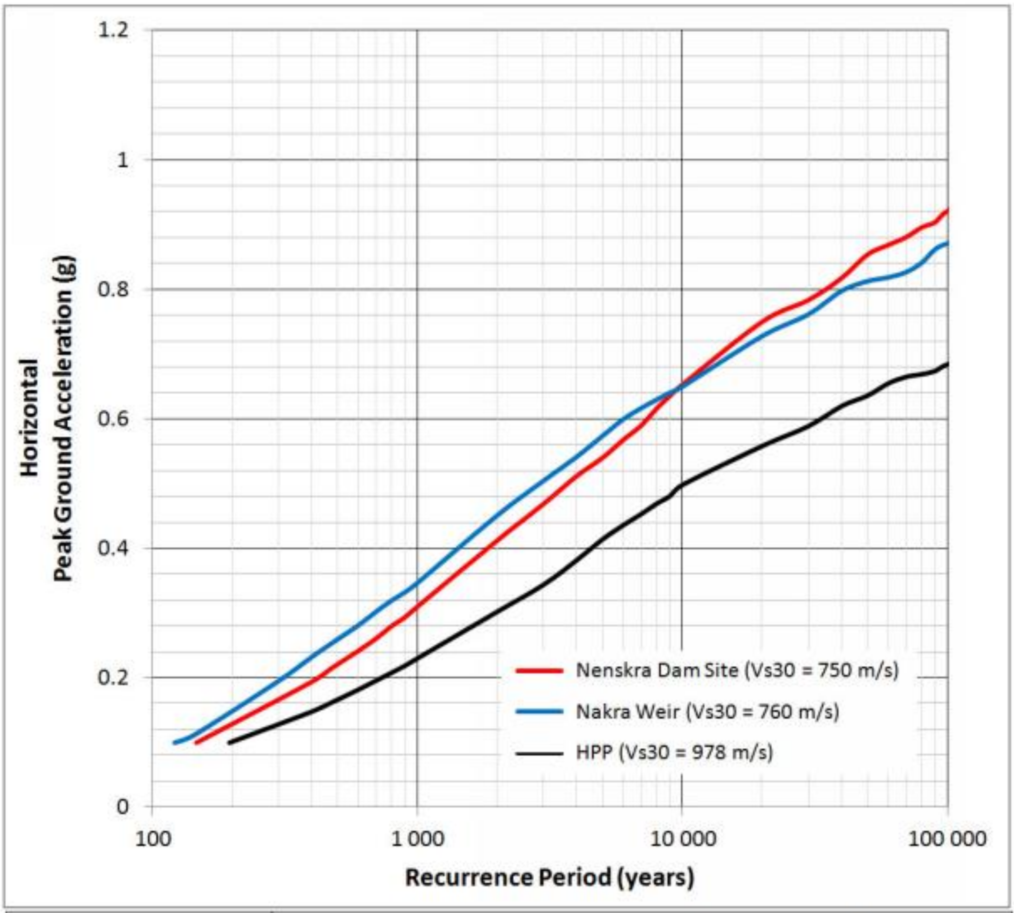
The intensity of earthquake induced ground motion at a given location decreases with increasing distance to the source of the earthquake. The Earthquake Hazard Analysis has used Ground Motion Prediction Equation (GMPE) published in specialised scientific papers to compute ground motion at the Project site. The GMPE used is that developed by Akkar et al (2013).

Calculation of ground motion parameters at site

Probabilistic seismic hazard analysis were carried out using the WCSZ source model illustrated in Figure A4-3 and with the GMPE developed by Akkar et al, 2013 for the determination of horizontal peak ground accelerations.

A Monte-Carlo analysis was used to determine magnitude and frequency of ground motion at the Project site, assuming a maximum seismic event with a Moment magnitude (Mw) of 7.5.

The hazard curves and the horizontal Peak Ground Accelerations (PGA) are presented in Figure A4-5.



Recurrence Period (years)	Horizontal peak ground acceleration (g)		
	Nenskra Dam Site	Nakra Weir	HPP
145 (OBE2)	0.10	0.11	0.10
475 (OBE1)	0.22	0.25	0.16
1000	0.31	0.35	0.23
3000 (SEE)	0.47	0.50	0.34
5000	0.54	0.57	0.41
10000 (so-called MCE)	0.65	0.63	0.50
20000	0.75	0.73	0.56

Source: Nenskra HPP Earthquake Hazard Assessment

Figure A4-5: Probabilistic hazard recurrence curves

Reservoir triggered seismicity

The information presented in the following paragraphs is taken from the Project's Earthquake Hazard Analysis. The RTS is of concern for two reasons; firstly with respect to dam stability and the need for the dam criteria to take into account seismic load including those resulting from RTS, and secondly regarding the impact of RTS on the local communities.

There is general scientific consensus that there is a relationship between creation of some large dam-reservoirs and a detectable change the frequency of seismic events. Field observations and scientific research has found that the strength of such reservoir-triggered earthquakes ranges from damaging earthquakes (Talwani, 1997) to micro-seismic emissions (Chander and Sarkar, 1993). In view of this and the recommendations of ICOLD, the possibility of Reservoir Triggered Seismicity (RTS) in the Nenskra Project area is consequently a phenomenon that is studied by the Project and RTS has been studied as part of the Project's Earthquake Hazard Analysis.

Lessons learnt on a worldwide scale

In a number of cases, the impounding of large and deep man-made reservoirs has triggered earthquakes large enough to be of significance to engineering projects and civil safety. S.K. Guha (2001) mentions that only 0.63 percent of the world's largest 11,000 dams higher than 10 metres have induced seismicity. On the other hand, the percentage reaches about 10 and 21 percent of the reservoirs deeper than 90 metres and 140 metres respectively.

Records (Guha, 2001) list 11 cases where the largest triggered earthquake had a magnitude of 5 or more. However, in only one case (Koyna, India, 1967), were damages inflicted to the dam severe enough to be of concern and this was related to the unusual design which was unsuitable for the seismic loading. These 11 cases represent only a small fraction of the large and deep artificial reservoirs in the world. Of course, many more reservoirs produced RTS in the form of small to very small quakes, posing no serious threat to the dams and public safety.

It is generally accepted that earthquakes are triggered by reservoir impoundment by either (i) the weight of the water on the earth's crust may cause movements on a fault, or (ii) the change in pore pressure due to water infiltration may have triggered slip on a fault. Consequently, depth and size of the reservoirs are major factors determining the size of the induced seismic activity. At depths greater than several kilometres (typical depths of earthquake generation), both the weight effects and the pore pressure effects are small. This is why it is believed that the crust beneath the reservoir must be critically stressed by tectonic forces and zones of weakness (faults) must be present for RTS to occur. The reservoir merely adds a small perturbation to the state of stress and triggers fault displacement, thus earthquake. Such earthquake would have occurred anyhow at a later date under the natural conditions of stress accumulation. The presence of the reservoir only hastened its occurrence. Also, the intensity of the RTS will not be greater than the intensity of seismic events without the presence of the reservoir.

The incidence of even very small increments of stress is well illustrated by the fact that, in several well documented cases of RTS, earthquakes tend to occur in close time relationship with sharp changes in reservoir level, even of moderate amplitude, rather than at maximum reservoir level. Rate of level variation is also important, and Gupta (1985, 1992) recommends that, where controllable, smooth emptying/refilling operation should be implemented and recommends filling rates of less than 12 metres per week.

As regards the factors likely to influence the level of RTS hazard, Baecher and Keeney (1982), summarizing the results of a worldwide study, mentioned that the occurrence of RTS would increase:

- With increasing reservoir depth;
- With increasing reservoir volume;
- When active fault is present in the vicinity of or across the reservoir;
- Among reservoir on sedimentary strata, rather than granitic, metamorphic or volcanic basement;
- Among reservoir on carbonate strata, rather than any other sedimentary strata, and
- Among reservoir in areas of extensional tectonics.

Assessment of RTS hazard at Nenskra

The largest earthquakes (magnitude greater than 6) on a worldwide scale reported in literature have been associated with reservoir depths in excess of 100 metres. As regards reservoir volume, most reported cases of RTS have been associated with impoundments smaller than the project reservoir. However, when considering the natural stress environment of the Nenskra reservoir and the nature of the underlying rocks, the conditions appear relatively favourable for minimising the scale of potential RTS at the Nenskra reservoir. In a context of compressive horizontal stress with reverse faulting mechanism, the increase of the vertical load will have a stabilizing effect and the natural permeability of the crystalline basement is expected to be very low, and infiltrations at depth will be minimal if any. Nevertheless, the possibility of occurrence of some RTS cannot be fully excluded. There are at present no feasible way to assess the maximum magnitude of RTS earthquakes, but events with a magnitude of 4.5 or less on a Moment Magnitude scale (equivalent to 4.5 on the Richter Scale) and possibly slightly more must be regarded as possible. To put this into context, earthquakes with a magnitude in the range of 3 to 3.9 are classed as “minor” and magnitudes in the range of 4 to 4.9 are classed as “light”. Seismic events in the range of 2.5 to 5.4 are often felt, but do not cause damage

Consequences of Nenskra Project RTS events

The Nenskra dam is in an area prone to seismic activity and any seismic events experienced in the region in the first few years after impoundment could be attributed to RTS whether true or not. This effect cannot be easily mitigated but it is a risk that is recognised by the Project Company.

Effects on the dam structure

The conclusion of the RTS section of the project’s Earthquake Hazard Assessment is that any RTS events will be of little consequence - if any - for the dam itself. The maximum magnitude a RTS event will be inferior to that of the OBE-1 and MCE for which the dam structure is designed to resist (see Figure A4-5).

Triggering of other naturally hazardous events

An RTS event could have a knock-on effect on slopes above the dam and the reservoir and could trigger events such as avalanche, slope instability and rockfall.

Effects on private houses

In terms of consequences of RTS on local communities, an RTS with a magnitude less than 4.5 is not expected to cause damage to buildings or structures.

Annex 5. Summary of slope stability assessment

A potential area of slope instability in the area of the future reservoir has been identified and evaluated. A field examination was made in August 2016 including a helicopter overflight. The area is located in the middle right slope approximately 2.5 kilometres upstream of the dam area.

An aerial view of the area of interest is provided in Figure A5-1. The area extends from an area above the future reservoir full supply level (1,440 metres asl) to the upper slope (2,330 metres), where the vegetation changes from forest to grass land. The change in vegetation coincides with a change in slope inclination and geological conditions:

- The lower, forested part is steeper (40 degrees) and is composed of bedrock with a variable soil cover made of a mix of glacial deposits and slope debris.
- The upper, grass covered part is less inclined (30 degrees), its substratum is composed of sub-outcropping bedrock with a thinner soil cover principally made of glacial deposits and pre-glacial erosion remnants.

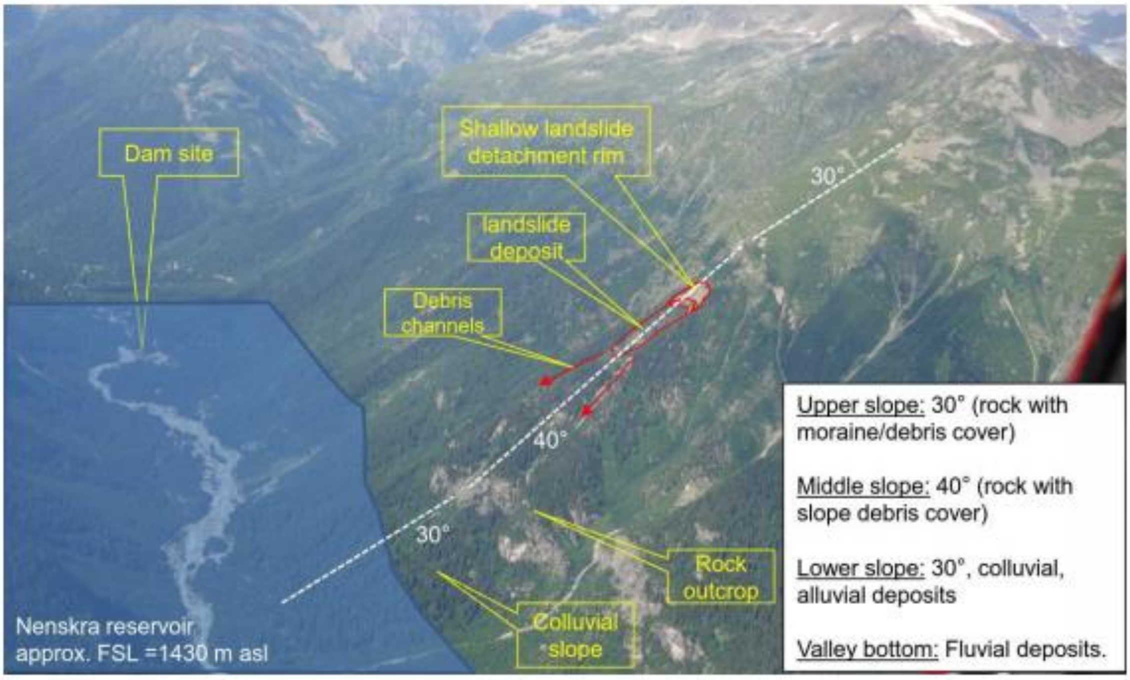


Figure A5-1: Aerial view of the area of uncertain slope stability

The geological model that has been developed for the area of interest takes into account the following elements:

- The slope is formed of the bedrock lithologies of the Nakra complex.
- The slope has a graduated geometry, with slopes varying from 30 to 40 degrees, and there is a section with a steep rock face/outcrop.
- In the middle and upper slope the soil cover is rather thin, reaching probably 10 to 20 metres and is composed of a mixture of glacial deposits and slope debris. The alluvial/colluvial deposits in the lower part of the slope are considerably thicker. The valley bottom is covered by fluvial and probably underlying glacial deposits that probably reach more than 100 metres.

- In the middle slope, at 2,000 m asl there is a collapsed soil landslide. It has a surface of about 125 x 200 metres and a volume of roughly 250,000 cubic metres. There are a few debris channels in the downslope end of the slide, indicating sparse episodic erosion.
- At the frontal rock face outcrop in the lower part of the slope, no larger signs of recent rock detachments are visible.
- The reservoir level is at 1,430 metre asl and 150 -200 metres below the base of the rock face. The final colluvial belt underneath the rock face shows intact tree vegetation which does exclude recent debris flow or landslide activities reaching the valley floor in the last 30 - 50 years, thus putting time limits for the return period of such possible natural hazard scenarios to T>50 years.

As a conclusion of the analyses that were performed the following key issues of the potential landslide area are explained in more depth:

- *Nature and volume of instability*. The analyses conclude in 2 instability mechanism. (i) The rather superficial landslide in the middle slope is a soil slide, with dimensions of 125 x 200 x 10 metres (250,000 cubic metres). It may be decomposed by sporadic debris flow at the tow of the soil slide mass (ii) Limited break-offs of rock material at the rock face in the middle slope cannot be excluded. However, there is no evidence for a deeper reaching rock slide or a general slope instability of the bedrock.
- *Instability scenarios*. The instability scenarios are occasional debris flows at the toe of the soil slide mass. They are triggered by periodic heavy water input into the slope (snow melt, heavy rainfall). Volumes may be around 10,000 cubic metres. An additional instability scenario proposes local break-offs of rock mass volumes at the frontal rock face. Estimated volumes may reach 10,000 cubic metres.
- *Fundamental cause*. The geological, geomorphological and radar interferometry analyses have shown that the phenomena are limited to a superficial extent. No evidence could be found for deeper-seated instabilities that affect the bedrock (rock slides). Since the glacial retreat the area is uncovered and is now exposed to atmospheric and other influences and is subject to local instabilities (soil instability and break-offs from rock face).
- *Initial triggering cause*. The soil landslide is located in the superficial soil cover in the change of slope from 30 - 40 degrees. A slope inclination of 40 degrees probably brings the slope, in combination with particularly heavy snow melt events, locally to its stability limit.
- *Driving forces*. The driving forces are those that have led to the initial slope instability. Particularly heavy snow melts or heavy rain may contribute to further events of slope instability. These are likely to be sporadic debris flow events starting from the toe of the soil slide mass and proceeding along the debris channels, reaching the lower part of the slope and the valley bottom. The rock mass break-offs are likely to be triggered by events of snow melt, heavy rainfall of freeze-thawing cycles.
- *Consequences*. The instability scenarios of debris flows that decompose the landslide mass at its toe and the limited break-offs of rock material have been evaluated in terms of possibly triggered flood waves. The waves are not capable to overtop the dam.

Overall no evidence has been found to suggest the possibility of general, larger-scaled slope instability.

Two possible slope instability scenarios have been studied to evaluate the consequences of a small superficial landslide on the reservoir and dam:

- Scenario 1: Decomposition of the landslide mass by debris flows that travel along the debris channels. A volume of 10,000 cubic metres is considered.
- Scenario 2: Rock mass break-offs of 10,000 cubic metres from the frontal rock face.

Both considered scenarios may cause impulse waves in the reservoir. The methodology developed by SFOE (2009) has been used to assess the potential of such impulse waves to overtop the dam and it was found that the maximum un-up at the dam as a result of the impulse waves was 3.3 metres, whereas the freeboard in 6 metres. Consequently, no overtopping as a result of impulse waves is expected.

In addition to an assessment of the slope stability by **satellite radar interferometry** was conducted to evaluate if any ground movements due to slope instabilities have recently occurred. This method is based on the comparison of satellite synthetic aperture radar images (SAR) to produce maps of surface deformations using differences in the phase of the waves returning to the satellite (Hansen, 2002). The analysis has confirmed that there is no evidence to suggest large scale slope instability.

Annex 6. Summary of risk management programme

Summary of risk management programme

Hazard In decreasing order of priority	Unwanted events	Studies completed	Studies still to be performed	Timing	Safeguard measures to be designed	Timing
1. Extreme flood event	Dam overtopping – leading to dam failure	Hydrological studies and definition of PMF	Climate Change risk assessment Review by OE, LTA and IPoE	H2 2017 / H1 2018	Detailed design of flood control structures with PMF capacity Development of operational procedures Review by OE, LTA and IPoE	H1 2018
2. Earthquake	Dam instability – leading to dam failure	Earthquake Hazard Assessment - definition of MCE Physical and numerical modelling of dam structure stability	N/A	N/A	Detailed design of structures to resist MCE Detailed design of buildings and facilities to comply with Project's seismic design criteria, in alignment with Georgian codes/standards and Good International Practice Development of operational procedures Design of monitoring system Review by OE, LTA and IPoE	H1 2018
3. Avalanche / debris flow	Blockage of spillway, bottom outlet or headrace tunnel portals – in the event of a flood event could cause dam overtopping and dam rupture	Natural hazards risk assessment	Detailed natural hazard risk assessment for all construction camps and technical installations to be completed before camps and installations constructed. Avalanche / debris flow studies – including modelling - to determine estimate quantities potentially mobilised, paths taken and structures at risk Consideration of climate change risk assessment in the avalanche/debris flow studies Review by OE, LTA and IPoE	H1 2018	Design of avalanche / debris flow protection measures for permanent structures and worksites Design of avalanche / debris flow protection measures for construction camps and technical installations Design of monitoring and alarm systems Development of operational procedures Review by OE, LTA and IPoE	H1 2018
	External erosion of dam structure (or coffer dam) leading to instability and dam rupture	Natural hazards risk assessment				
	Temporary construction camps and technical installations and work sites impacted by avalanche / debris flow	Preliminary natural hazards risk assessment for construction camps and technical installations				
	Impulse wave generated in reservoir causing either (i) dam overtopping and rupture or (ii) spillage and a high flow in the Nenskra river	Natural hazards risk assessment	Study of potential impulse waves generated by avalanche and risk of dam overtopping	H1 2018	Design of monitoring and alarm systems Development of operational procedures Review by OE, LTA and IPoE	H1 2018
4. Slope instability	Landslide and impulse wave generated in reservoir causing either (i) dam overtopping and rupture or (ii) spillage and a high flow in the Nenskra river	Natural hazards risk assessment Radar interferometry study to establish recent movement of the slope Review by OE, LTA and IPoE	N/A	N/A	Design of monitoring and alarm systems Development of operational procedures Review by OE, LTA and IPoE	H1 2018

Summary of risk management programme

Hazard In decreasing order of priority	Unwanted events	Studies completed	Studies still to be performed	Timing	Safeguard measures to be designed	Timing
5. Dam failure	Dam failure	Tentative qualitative risk assessment Preliminary Emergency Preparedness Plan (EPP)	Detail dam failure risk assessment in alignment with ICOLD methodologies and including coffer dam. Assessment of the risk of the failure of the Enguri dam as a result of the failure of the Nenskra dam using an ICOLD method and if necessary estimation of the consequences using flood modelling. Review by OE, LTA and IPoE	H1 2018	Emergency Preparedness Plan (EPP), including flood studies and flood mapping, and engagement with local communities Review by OE, LTA and IPoE	H1 2018
6. Bottom Outlet (BO) malfunction	Downstream flooding	Tentative qualitative risk assessment	Bottom outlet gate operation risk assessment in alignment with ICOLD methodologies Review by OE, LTA and IPoE	H1 2018	Design BO gate operating system Review by OE, LTA and IPoE	H1 2018
			Flood modelling for various discharges from bottom outlet Review by OE, LTA and IPoE	H1 2018	BO gate operating rules and procedures If and where required, design and build river flood protection works downstream of dam Include event in EPP Design warning systems Review by OE, LTA and IPoE	H1 2018
7. Rockfall	Nakra transfer tunnel outlet portal impacted by rockfall. Damage to structures injury to workers.	Natural hazards risk assessment	Detailed natural hazard risk assessment for all construction camps (see avalanche/debris flow above) Rockfall studies to determine estimate quantities potentially mobilised, paths taken and structures at risk Review by OE, LTA and IPoE	H1 2018	Design of rockfall protection measures for permanent structures and worksites Design of monitoring and alarm systems Review by OE, LTA and IPoE	H1 2018
	Temporary construction camps and technical installations and work sites impacted by rockfall	Preliminary natural hazards risk assessment for construction camps and technical installations			Design of rockfall protection measures for construction camps and technical installations Design of monitoring and alarm systems Review by OE, LTA and IPoE	H1 2018
8. GLOF	Impulse wave generated in reservoir causing either (i) dam overtopping and rupture or (ii) spillage and a high flow in the Nenskra river (see dam rupture below)	Natural hazards risk assessment	N/A	N/A	N/A	N/A

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