# TECHNO-ECONOMIC ASSESSMENT STUDY FOR ROGUN HYDROELECTRIC CONSTRUCTION PROJECT

## PHASE II: PROJECT DEFINITION OPTION

## VOLUME 6: RISK ANALYSIS

**August 2014**

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# 1 ANTECEDENTS AND SCOPE

A risk analysis is presented in this volume as a closure of the Phase-II Studies of the ROGUN Hydropower Project. It constitutes a component of the Techno-Economical Assessment Studies (TEAS), developed at the level of a feasibility study and including the comparison of alternatives of dam height and of installed power capacity.

The Risk Analysis represents the crowning moment of the Project Assessment as it summarizes and qualifies the main topics that may affect the project technical feasibility, attractiveness and sustainability, detected during the development of the studies.

Three main phases are to be considered when developing a Risk Analysis: Identification, evaluation and management. The risk identification phase detects, describes and qualifies the causes as well as the potential effects. The risk evaluation phase quantifies those risks and compares their quotes to the tolerable or acceptable values that a person, a community or a population is ready to accept in view of the benefit he or they are expecting from the concerned goods or activities. And finally, the risk management phase is the one in which remedial or mitigation measures are proposed in order to reduce (as far as possible) the detected risks to an acceptable value and then implements those measures and ensures their successful follow up.

The document presented here describes the risk analysis performed by the TEAS Consultant for the Risk Analysis Workshop, planned to take place during the Paris meetings of May 2013~~.~~

The goal of the workshop was twofold: informing the Tajik officials and the World Bank representatives and experts about the methodology and the findings of the risk analysis, and also discussing with them the proposed levels of risk acceptability as well as the corresponding mitigation measures, looking for a common understanding and consensus, as far as possible.

During the Paris Meetings there was only the opportunity to describe the methodology and to inform about the major findings and proposed mitigation measures. The Consultant wishes then that the present document will be soon helpful to facilitate discussions on those subjects in the form of a workshop or any other way through which the BT and WB/PoE voices and opinions can be gathered and taken into account.

The present document describes the methodology used by the Consultant for the preparation of the Risk Analysis. It presents concepts, definitions, lists the major risks, proposes the valuation of each one of them (prior and after the mitigation measures) as well as the risk management procedures.

The current version of the Risk Analysis does not consider neither the Economic and Financial risks nor the Socio-political risks. Environmental risks are to be considered separately within the frame of the Environmental and Social Impact Assessment (ESIA).

## 2 TERMINOLOGY AND METHODOLOGY

Risk is considered here as a situation involving exposure to danger. The level of exposure is defined as the likelihood of occurrence of an unwanted event (cause) and the level or degree of danger is measured as the amount of damage if that unwanted event occurs (effect or impact). Risk is then measured as the product of the level of exposure (probability of occurrence) times the level of danger (amount of damage).

As the probability of occurrence is a non-dimensional value, risk is expressed in the same units as the amount of damage, evaluated under the hypothesis that the unwanted event occurs.

The *likelihood of occurrence* is directly linked to the phenomenon likely to produce an unwanted event. The causes shall be classified into several categories, and likelihood of occurrence is estimated according to statistical data (historical database), and the experience and expertise of the engineer.

The *consequences*, also referred to as impacts or effects, are ranked according to the estimated cost of damages (direct cost of repair or replacement as well as loss of gain) taking into account its geographical extent (project, local, regional…). Impacts shall be classified according to the impacted facilities of the Rogun hydroelectric scheme (dam, power plant, hydraulic system…).

# 3 RISK IDENTIFICATION

## 3.1 Identified risks

The first step of the risk analysis consists of identifying and listing all the possible risks linked to the project. This step is carried out by the consolidation of the learned knowledge on the various aspects of the project, by the different participants involved in the project, and the documentation of previous studies.

In order to normalize the analysis, a classification of the different categories of causes and effects is performed.

Causes are classified in four different “families” of sources of potential unwanted events: natural causes, technical causes, economic-financial and socio-political causes.

The family of natural causes includes all the phenomena normally described by the natural sciences strongly related to weather and climate, hydrology, geology, tectonics, seismicity, geo-technics, rock mechanics, etc.

Technical causes are mostly related to the way in which engineers and technicians do use those data, first to understand the local and regional characteristics of nature and then to design, construct, operate, maintain or decommission or even dismantle the project under consideration.

The economic and financial causes under consideration are the external market circumstances, trends or changes (gradual or abrupt) that may affect quality, cost, benefits and delays of the project. In the current analysis this family of causes has not been considered.

The socio-political causes are those born by decisions at a local, national, regional or higher level, produced in the host country or outside of it, that may affect the normal (planned) development of the project and consequently its foreseen output. In the current analysis this family of causes has not been considered.

As indicated in Table 3-1, causes are defined up to three levels of detail for each one of the above mentioned families of causes.

| LEVEL 1 | LEVEL 2 | LEVEL 3 |
|---|---|---|
| **Natural** | Hydrology | Water availability |
| | | Sediments |
| | | Construction floods |
| | | Rare floods |
| | | GLOFs |
| | Geology / Geotechnics / Geomechanics | Salt dissolution in dam foundation |
| | | Salt intrusion in RB |
| | | RB-DS important instability |
| | | Long-term creeping of faults |
| | | Mudflows from Obishur R. and other streams |
| | | Leakage from reservoir |
| | | Co-sismic displacements |
| | | Reservoir rim slope instability |
| | | Dam material: inappropriate survey, inadequate material |
| | | Structures-Caverns: rock excavation |
| | | Co-sismic displacements |
| | | Dam excavation: slope instabilities |
| | Tectonics-Seismicity | Earthquakes |
| | Weather | Temperature |
| | | Rain |
| | | Snow |
| | | Ice |
| **Technical** | Design | Evaluation of natural conditions |
| | | Design studies |
| | | Maximum head in tunnels |
| | Construction | Diversion/Tailrace tunnels: construction quality |
| | | Construction experience and technics. Equipment |
| | | Construction schedule |
| | | Contractual issues |
| | Fabrication | Fabrication technics, materials, schedule |
| | | Contractual issues |
| | Maintenance & Operation | Maintenance: Experience of personnel. Schedule and planning |
| | | Operation: Experience of personnel. Schedule and planning |
| | | Monitoring programs |
| | Decommissioning | Opportunity - Procedures |
| **Economico-Financial** | Market prices | Materials and equipment: Present and future conditions. Availability. Inflation. |
| | Energy demand | Mid- and long term changes in demand |
| | Funding | Availability of funds. Rates. Insurances. |
| **Socio-Political** | Social | Resettlement conditions |
| | Political at National level | Taxation |
| | | Political decisions |
| | Political Regional level | Poor plan for shared resources |
| | | Reservoir operation / filling not agreed |

**Table 3-1: Classification of Causes**

## 3.2 Identified impacts

In a similar manner, the components of the project likely to be impacted are classified in six different systems: dam system, reservoir system, , flood management system and power system, construction and access systems.

The following Table 3-2 illustrates the classification of the project components likely to be impacted by unwanted events.

| | | | |
|---|---|---|---|
| **Dam system** | Pre-cofferdam | **Flood management system** | Diversion Tunnels 1,2,3 |
| | Cofferdam | | Mid Level tunnels 1,(2) |
| | Stage 1 dam | | High level Tunnels 1, (2), (3) |
| | Main dam | | Surface spillway |
| **Construction site** | Workers accomodations | **Power & Energy system** | CW: Intakes |
| | Site equipments | | CW: Headrace tunnels |
| | Site plants | | CW: Power house & TH |
| **Reservoir system** | Reservoir rim | | CW: Tailrace tunnels |
| | Rogun city | | EM: Turbines |
| | Karstic structures | | EM: Generator |
| | Guilzidan fault area | | EM: Transformers |
| **Access** | Construction access | | EM: Cable galleries |
| | Permanent access | | EM: Switchyard |
| | | | EM: Transmission lines |
| | | | Energy production |

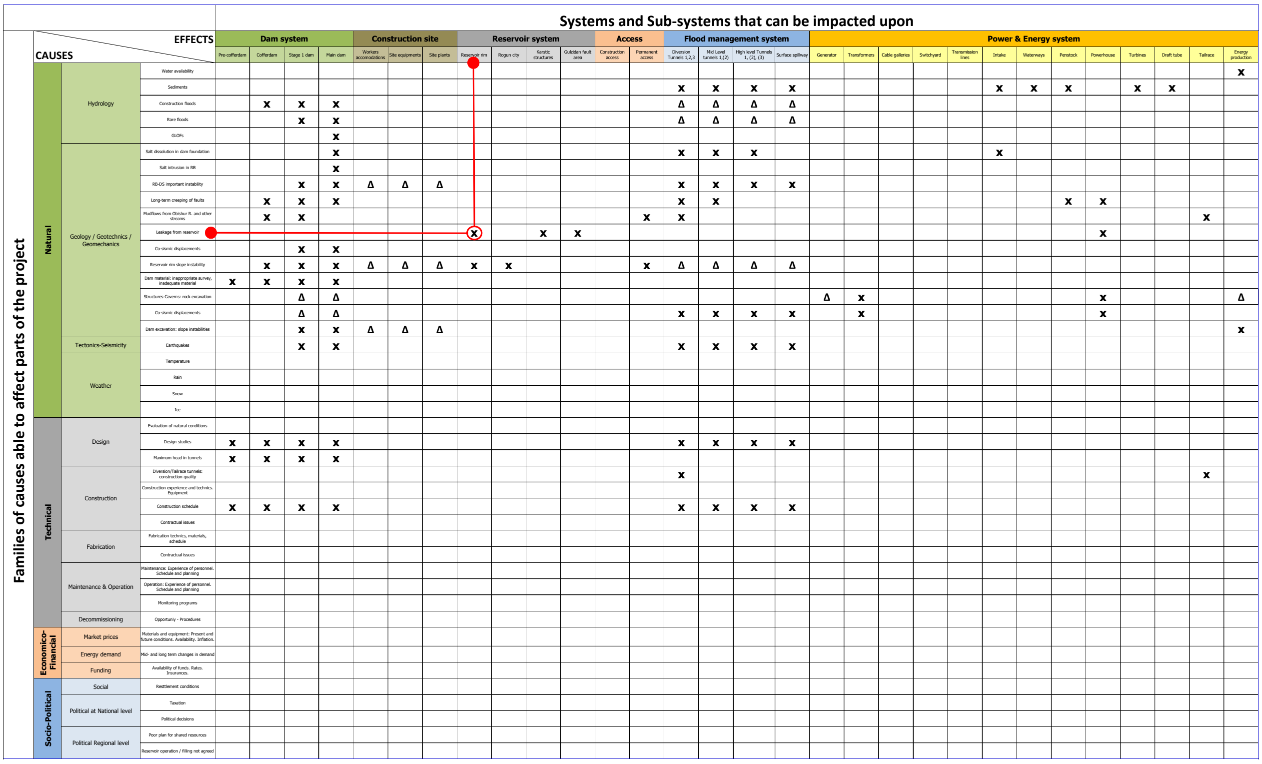
**Table 3-2: Classification of Project components**

These two classifications help to quickly get an overview of causes and impacts, and facilitate the synthesis of risk data.

The four families of causes (developed at three different levels of detail) and the six systems of project structures or functions (also developed at three levels of detail) are then brought to a matrix called **Interaction Matrix** in order to facilitate the finding of project risks, selected for further analysis.

Figure 3-1 shows a typical form of Interaction Matrix. The final matrix corresponding to the complete Risk Assessment is enclosed in Appendix 7.1Interaction Matrix.

Experts familiar with each one of the systems and sub-systems together with experts on the potential causes inspect the matrix and determine what causes may affect what systems. If it is found that there may be any potential risky interaction between a given cause and a certain project component (system, sub-system or lower) this is indicated in the interaction matrix (for instance, with an "X" in the corresponding cell). A specific "Risk Evaluation Sheet" is then developed for each case of potential risk identified in the Interaction Matrix.



Systems and Sub-systems that can be impacted upon

Families of causes able to affect parts of the project

| CAUSES | | EFFECTS | Dam system | | | | Construction site | | | Reservoir system | | | | Access | | Flood management system | | | | Power & Energy system | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pre-cofferdam | Cofferdam | Stage 1 dam | Main dam | Workers accomodations | Site equipments | Site plants | Reservoir rim | Rogun city | Karstic structures | Gulzidan fault area | Construction access | Permanent access | Diversion Tunnels 1,2,3 | Mid Level tunnels 1,(2) | High level Tunnels 1, (2), (3) | Surface spillway | Generator | Transformers | Cable galleries | Switchyard | Transmission lines | Intake | Waterways | Penstock | Powerhouse | Turbines | Draft tube | Tailrace | Energy production |
| Natural | Hydrology | Water availability | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | x |
| | | Sediments | | | | | | | | | | | | | | x | x | x | x | | | | | | x | x | x | | x | x | | |
| | | Construction floods | | x | x | x | | | | | | | | | | Δ | Δ | Δ | Δ | | | | | | | | | | | | | |
| | | Rare floods | | | x | x | | | | | | | | | | Δ | Δ | Δ | Δ | | | | | | | | | | | | | |
| | | GLOFs | | | | x | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Geology / Geotechnics / Geomechanics | Salt dissolution in dam foundation | | | | x | | | | | | | | | | x | x | x | | | | | | | x | | | | | | | |
| | | Salt intrusion in RB | | | | x | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | RB-DS important instability | | | x | x | Δ | Δ | Δ | | | | | | | x | x | x | x | | | | | | | | | | | | | |
| | | Long-term creeping of faults | | x | x | x | | | | | | | | | | x | x | | | | | | | | | | x | x | | | | |
| | | Mudflows from Obishur R. and other streams | | x | x | | | | | | | | | | x | x | | | | | | | | | | | | | | | x | |
| | | Leakage from reservoir | | | | | | | | x | | x | x | | | | | | | | | | | | | | | x | | | | |
| | | Co-sismic displacements | | | x | x | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Reservoir rim slope instability | | x | x | x | Δ | Δ | Δ | x | x | | | | x | Δ | Δ | Δ | Δ | | | | | | | | | | | | | |
| | | Dam material: inappropriate survey, inadequate material | x | x | x | x | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Structures-Caverns: rock excavation | | | Δ | Δ | | | | | | | | | | | | | | Δ | x | | | | | | | x | | | | Δ |
| | | Co-sismic displacements | | | Δ | Δ | | | | | | | | | | x | x | x | x | | x | | | | | | | x | | | | |
| | | Dam excavation: slope instabilities | | | x | x | Δ | Δ | Δ | | | | | | | | | | | | | | | | | | | | | | | x |
| | Tectonics-Seismicity | Earthquakes | | | x | x | | | | | | | | | | x | x | x | x | | | | | | | | | | | | | |
| | Weather | Temperature | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rain | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Snow | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Ice | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Technical | Design | Evaluation of natural conditions | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Design studies | x | x | x | x | | | | | | | | | | x | x | x | x | | | | | | | | | | | | | |
| | | Maximum head in tunnels | x | x | x | x | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Construction | Diversion/Tailrace tunnels: construction quality | | | | | | | | | | | | | | x | | | | | | | | | | | | | | | x | |
| | | Construction experience and technics. Equipment | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Construction schedule | x | x | x | x | | | | | | | | | | x | x | x | x | | | | | | | | | | | | | |
| | | Contractual issues | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Fabrication | Fabrication technics, materials, schedule | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Contractual issues | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Maintenance & Operation | Maintenance: Experience of personnel. Schedule and planning | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Operation: Experience of personnel. Schedule and planning | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Monitoring programs | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Decommissioning | Opportuniy - Procedures | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Economico-Financial | Market prices | Materials and equipment: Present and future conditions. Availability. Inflation. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Energy demand | Mid- and long term changes in demand | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Funding | Availability of funds. Rates. Insurances. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Socio-Political | Social | Resttlement conditions | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Political at National level | Taxation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Political decisions | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Political Regional level | Poor plan for shared resources | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Reservoir operation / filling not agreed | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Figure 3-1: Interaction Matrix

Only those risks having significant impacts on the Project have been selected at the level of the TEAS-Phase II for further evaluation.

In the next paragraphs it is explained how each one of the identified and selected risks is evaluated and compared to the tolerated level of risk and which mitigation measures are proposed to lower the level of risk down to and acceptable value.

Risk Sheets have been prepared in order to follow up the identification, evaluation and management of each one of the selected risks.

# 4 RISK EVALUATION

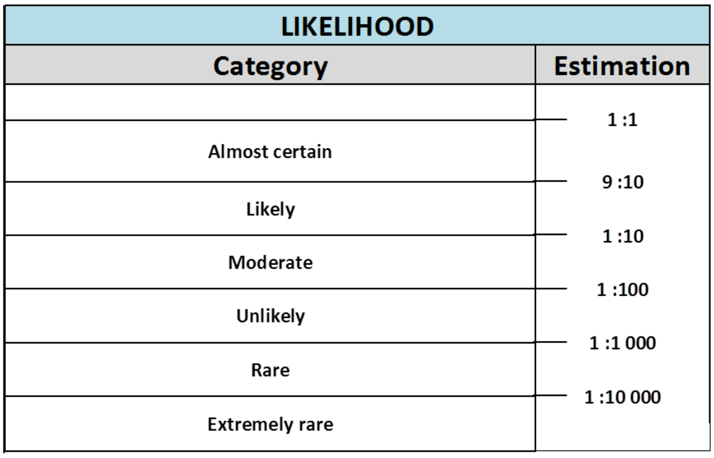
Risk evaluation is made by estimation of both the likelihood of occurrence of the unwanted event and the amount of damage able to occur, should the unwanted event occur.

## 4.1 Likelihood of an unwanted event

The likelihood of a given phenomenon is measured in terms of probability of occurrence “$P_{OCC}$”, i.e. how many unfavourable cases occur out of N events observed. It is expressed as “1 in N” or simply “1:N”.

A scale of likelihood has been established in order to facilitate the classification of the potential events under consideration. This classification is shown in the table ~~6~~4.1.

Phenomena considered as “almost certain” have a probability of occurrence higher than 90% or “9:10”. Phenomena considered as “likely” are located in the central portion of the frequency curve (histogram) ranging between 1:10 and 9:10. Phenomena called “moderate”, “unlikely”, “rare” and “extremely rare” do have probabilities of occurrence smaller than 1:10, 1:100, 1:1.000 and 1:10.000, respectively.



| LIKELIHOOD | |
|---|---|
| Category | Estimation |
| | 1 :1 |
| Almost certain | |
| | 9 :10 |
| Likely | |
| | 1 :10 |
| Moderate | |
| | 1 :100 |
| Unlikely | |
| | 1 :1 000 |
| Rare | |
| | 1 :10 000 |
| Extremely rare | |

**Table 4-1: Grades of likelihood of occurrence**

We have defined the probability of occurrence as the occurrence of one unwanted event out of N events observed (or out of N tests or trials performed). Even those phenomena having a low probability of occurrence can be observed if the number N of tests or trials becomes large.

In the field of large civil engineering projects (and particularly in the case of hydropower projects) “N” can be understood as the number of years of life of a given structure, subject to natural phenomena like floods, earthquakes, etc. Civil works in those projects may stand for several hundreds of years (even if they may no longer produce energy or other services). We say then that the project or the structure is exposed to several risks and we call their life span the “period of exposure” or “TE”.

Under such conditions, the chances of unfavourable natural phenomena to be observed become non-negligible and they may lead to important damages or even to the collapse of those structures.

On the other hand, those natural phenomena may be associated with the idea of “period of return”. That means that it has been observed repeatedly and that, in average, it returns every “TMR” years. (TMR = Mean Period of Return).

It becomes then evident that the longer the period of exposure TE of the project, the higher the chances of an important phenomenon with a large mean period of return TMR to occur. We can then correlate all the three playing parameters “$P_{OCC}$”, “TE” and “TMR” with the help of the following equation:

$$P_{OCC} = 1 - (1 - \frac{1}{TMR})^{TE}$$

The table below presents a correlation of the three variables involved assuming, as an example, a period of exposure of 100 years and relating the concept to the probability of floods.

<table>
<tr><th colspan="6">Correlation between Likelihood, Probability of Occurrence and Mean Period of Return</th></tr>
<tr><th colspan="6">for a Period of Exposure TE = 100 years</th></tr>
<tr><th>Likelihood</th><th>$P_{OCC}$</th><th>TMR (years)</th><th>Comments, Examples</th><th>Gumbel Variate (Gv)</th><th>Ratio of Gv to Gv for 1:10,000</th></tr>
<tr><td>Likely</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>1:10</td><td>950 ≈ 1,000</td><td>The 1 in 1,000 year flood</td><td>6,86</td><td>0,74</td></tr>
<tr><td>Moderate</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>1:100</td><td>9 950 ≈ 10,000</td><td>The 1 in 10,000 year flood</td><td>9,21</td><td>1</td></tr>
<tr><td>Unlikely</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>1:1,000</td><td>99 950 ≈ 100,000</td><td>- - -</td><td>11,51</td><td>1,25</td></tr>
<tr><td>Rare</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>1:10,000</td><td>999 950 ≈ 1,000,000</td><td>Order of magnitude of a PMF</td><td>13,82</td><td>1,50</td></tr>
<tr><td>Extremely Rare</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

**Table 4-2: Grades of likelihood of occurrence**

## 4.2 Estimate of the Amount of Damage

The estimation of the impact of a given event is based on the estimation of the cost of damages generated by the event, and the human lives potentially endangered. As presented in Table 3-2, potentially impacted components of Rogun HPP scheme are listed, and the severity of an impact is evaluated on a graded scale defined as follows:

| IMPACT | |
|---|---|
| **Category** | **Estimation [M$]** |
| Insignificant | 1 |
| Minor | 100 |
| Moderate | 1 000 |
| Major | 10 000 |
| Extreme | |

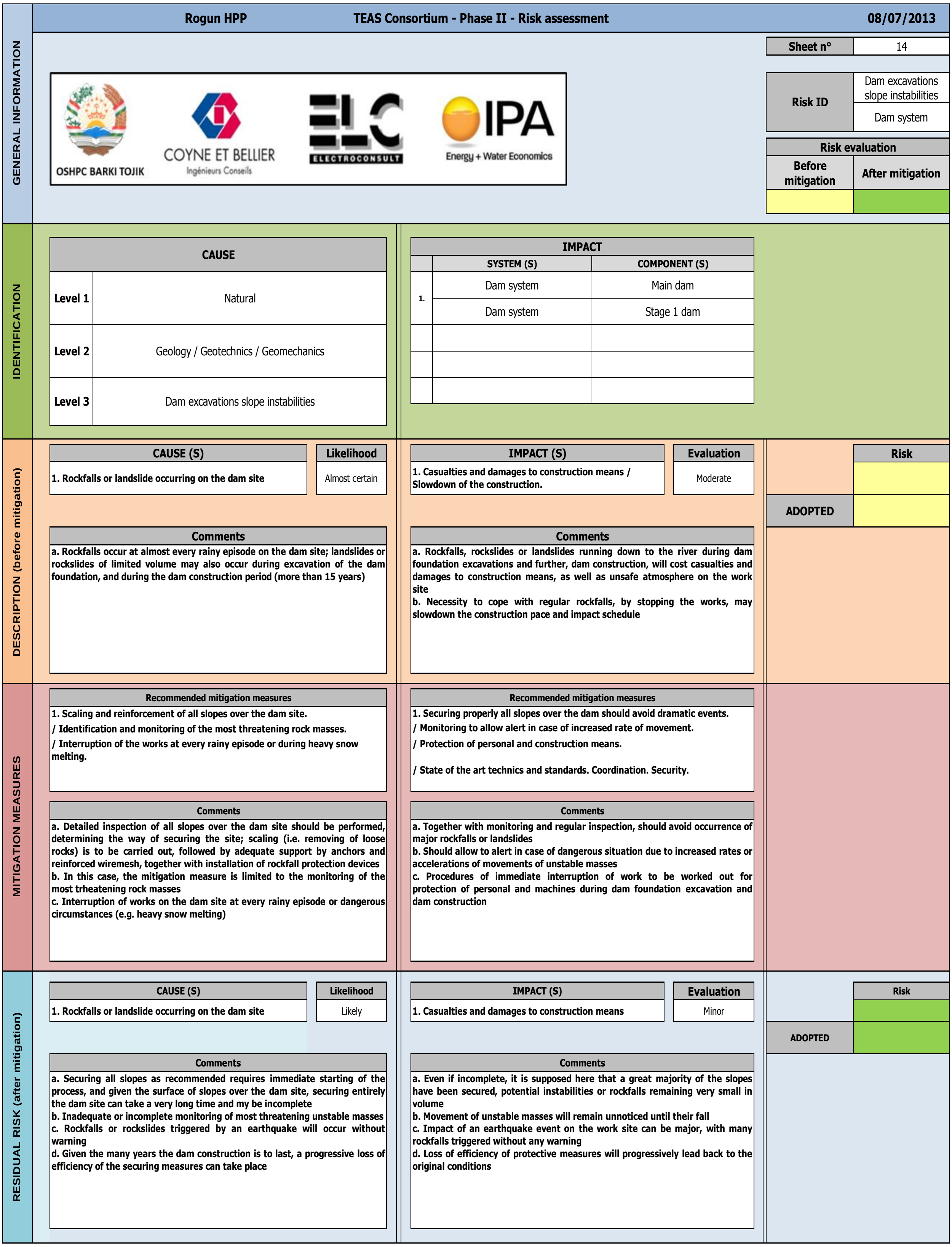
**Table 4-3: Grades of impact**

## 4.3 Risk estimation

The estimation of the risk is done by combining (multiplying) the estimates of likelihood of occurrence of the unwanted event and the estimate of its impacts, should it occur.

Such a combination requires that all the causes likely to produce a given impact are evaluated in order to select the most important risk. In the same manner, if a given cause is likely to produce various impacts, the most important risk is to be considered.

In order to organize and present data and information relative to this risk assessment, “risk sheets” have been implemented. In this way, each identified risk is analysed in a dedicated sheet. Figure 4-1 presents a typical risk sheet. The risk sheets established for each one of the risks under consideration (number 26) are shown in appendix “0 ”.



**Rogun HPP** **TEAS Consortium - Phase II - Risk assessment** **08/07/2013**

**GENERAL INFORMATION**

| | |
|---|---|
| **Sheet n°** | 14 |
| **Risk ID** | Dam excavations slope instabilities<br>Dam system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

**IDENTIFICATION**

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Dam excavations slope instabilities |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Main dam |
| | Dam system | Stage 1 dam |
| | | |
| | | |
| | | |

**DESCRIPTION (before mitigation)**

| **CAUSE (S)** | **Likelihood** | **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|---|---|
| 1. Rockfalls or landslide occurring on the dam site | Almost certain | 1. Casualties and damages to construction means / Slowdown of the construction. | Moderate | 🟨 |

**ADOPTED** 🟨

**Comments**

a. Rockfalls occur at almost every rainy episode on the dam site; landslides or rockslides of limited volume may also occur during excavation of the dam foundation, and during the dam construction period (more than 15 years)

**Comments**

a. Rockfalls, rockslides or landslides running down to the river during dam foundation excavations and further, dam construction, will cost casualties and damages to construction means, as well as unsafe atmosphere on the work site

b. Necessity to cope with regular rockfalls, by stopping the works, may slowdown the construction pace and impact schedule

**MITIGATION MEASURES**

**Recommended mitigation measures**

1. Scaling and reinforcement of all slopes over the dam site.

/ Identification and monitoring of the most threatening rock masses.

/ Interruption of the works at every rainy episode or during heavy snow melting.

**Recommended mitigation measures**

1. Securing properly all slopes over the dam should avoid dramatic events.

/ Monitoring to allow alert in case of increased rate of movement.

/ Protection of personal and construction means.

/ State of the art technics and standards. Coordination. Security.

**Comments**

a. Detailed inspection of all slopes over the dam site should be performed, determining the way of securing the site; scaling (i.e. removing of loose rocks) is to be carried out, followed by adequate support by anchors and reinforced wiremesh, together with installation of rockfall protection devices

b. In this case, the mitigation measure is limited to the monitoring of the most trheatening rock masses

c. Interruption of works on the dam site at every rainy episode or dangerous circumstances (e.g. heavy snow melting)

**Comments**

a. Together with monitoring and regular inspection, should avoid occurrence of major rockfalls or landslides

b. Should allow to alert in case of dangerous situation due to increased rates or accelerations of movements of unstable masses

c. Procedures of immediate interruption of work to be worked out for protection of personal and machines during dam foundation excavation and dam construction

**RESIDUAL RISK (after mitigation)**

| **CAUSE (S)** | **Likelihood** | **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|---|---|
| 1. Rockfalls or landslide occurring on the dam site | Likely | 1. Casualties and damages to construction means | Minor | 🟩 |

**ADOPTED** 🟩

**Comments**

a. Securing all slopes as recommended requires immediate starting of the process, and given the surface of slopes over the dam site, securing entirely the dam site can take a very long time and my be incomplete

b. Inadequate or incomplete monitoring of most threatening unstable masses

c. Rockfalls or rockslides triggered by an earthquake will occur without warning

d. Given the many years the dam construction is to last, a progressive loss of efficiency of the securing measures can take place

**Comments**

a. Even if incomplete, it is supposed here that a great majority of the slopes have been secured, potential instabilities or rockfalls remaining very small in volume

b. Movement of unstable masses will remain unnoticed until their fall

c. Impact of an earthquake event on the work site can be major, with many rockfalls triggered without any warning

d. Loss of efficiency of protective measures will progressively lead back to the original conditions

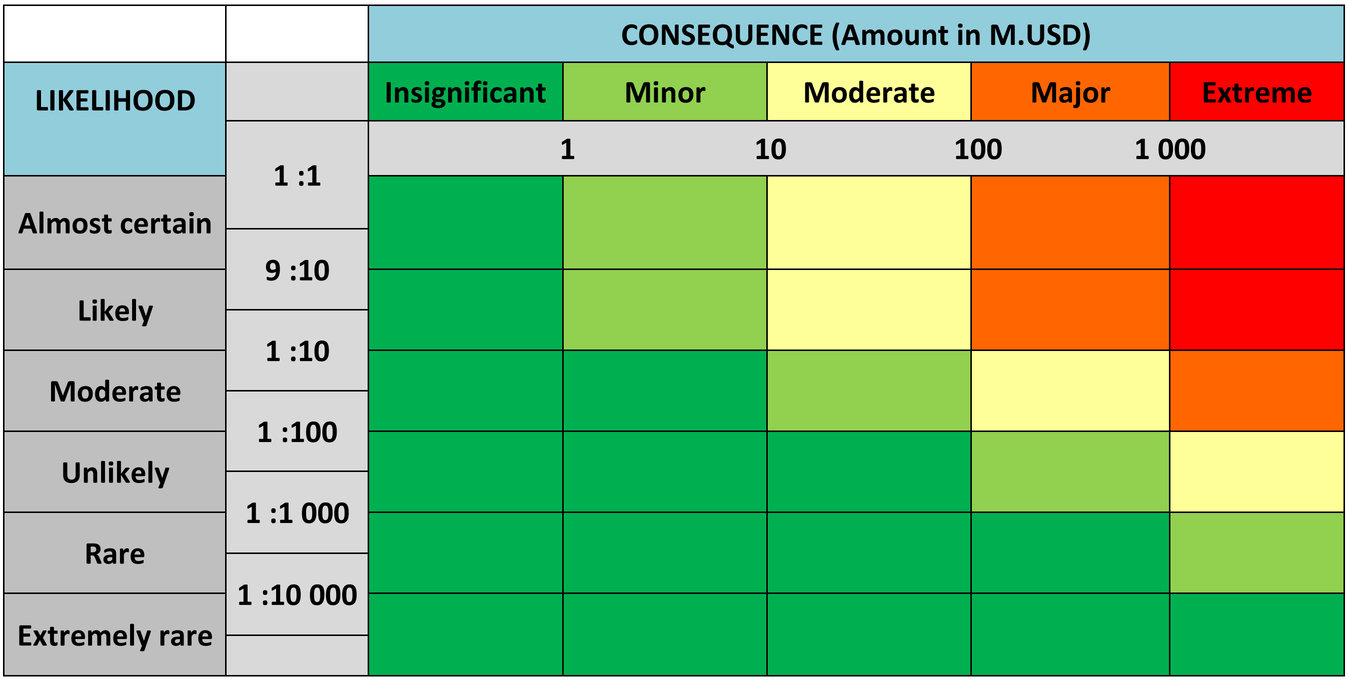
Figure 4-1: Typical RISK SHEET

The risk sheets are structured in five sections as follows:

| | |
|---|---|
| **General information** | Summarized information: Risk I.D., sheet number, type of risk. |
| **Identification** | Both causes and impacts are identified according to previously defined lists. |
| **Evaluation**<br>**(Before mitigation)** | Both causes and impacts are described and evaluated in order to estimate the risk. |
| **Mitigation measures** | Possible mitigation measures for the risk are detailed in this section. |
| **Residual risk evaluation (After mitigation)** | The risk is re-evaluated by taking into consideration the mitigation measures. The residual risk is to be compared to the initial estimation of the risk in order to assess the efficiency of mitigation measures. |

**Table 4-4: Description of the various sections of risk sheets**

The gradation adopted for the risk estimation is deduced from the classifications of likelihood and impact. By combining (multiplying) the probability of occurrence with the cost of impacts, the risk is estimated. The likelihood or probability of occurrence being a non-dimensional magnitude, risk takes the same units as the impact that it may produce. Risk is then expressed in M.$.



| | | **CONSEQUENCE (Amount in M.USD)** | | | | |
|---|---|---|---|---|---|---|
| **LIKELIHOOD** | | **Insignificant** | **Minor** | **Moderate** | **Major** | **Extreme** |
| | **1 :1** | | **1** | **10** | **100** | **1 000** |
| **Almost certain** | **9 :10** | 🟩 | 🟢 | 🟨 | 🟧 | 🟥 |
| **Likely** | **1 :10** | 🟩 | 🟢 | 🟨 | 🟧 | 🟥 |
| **Moderate** | **1 :100** | 🟩 | 🟩 | 🟢 | 🟨 | 🟧 |
| **Unlikely** | **1 :1 000** | 🟩 | 🟩 | 🟩 | 🟢 | 🟨 |
| **Rare** | **1 :10 000** | 🟩 | 🟩 | 🟩 | 🟩 | 🟢 |
| **Extremely rare** | | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 |

**Table 4-5: Risk estimation table [M$]**

The associated colours are chosen in order to reflect the severity of a risk, from the deep green, to the bright red, following the impact gradation.

# 5 RISK ASSESSMENT

The current chapter presents the development and the results of the risk assessment, based on the methodology described above.

## 5.1 Interaction matrix

In order to facilitate the identification of risks to be considered, an interaction matrix was used, combining the predetermined families of potential causes of risk (with three levels of detail) with the predetermined project systems and sub-systems able to be affected by those causes.

Appendix “7.2 Interaction Matrix” shows the interaction matrix used in the current risk analysis. Twenty six cases of potential risk have been selected for further analysis.

The 26 cases selected for further study are listed in appendix “7.2 Risk summary”. In the same table indication is given of the level of risks before and after application of the mitigation measures.

## 5.2 Risk Sheets

Twenty six Risk Sheets have been worked out as described in the former chapters in order to evaluate the likelihood of causes, the amount of impacts, the consequent risk, to propose and describe mitigation measures and finally to evaluate the residual risk, after the application of the mitigation measures.

The resulting Risk Sheets are shown in Risk summary.

It is to be indicated that the following process has been followed for the preparation of each Risk Sheet. The goal of this process is to ensure overall coherence and technical consistence and to minimize subjectivity:

- Each Risk Sheet had a nominated person associated, responsible for filling it up. That nominated person was, in most of the cases, an expert on matters related to the effects but always also familiar with causes.
- Two experts were associated to a single Risk Sheet, one for the causes and another one for the effects, in case of complexity.
- Ranges of likelihood and levels of impact, as defined above, were to be respected strictly in order to keep coherence in the overall analysis. The corresponding spread-sheets had been prepared in order to satisfy this condition.
- Prepared Risk Sheets were then checked one by one by the person in charge of the Risk Analysis.
- The reviewed/revised Risk Sheets were then controlled and checked by a technical committee composed by the Project Manager, the Technical Advisor and the respective Experts.

This process, internal to the TEAS Consultant, is to be followed by a Risk Workshop with participation of the Tajik Officials and the World Bank Team Members and Experts. The goal of it is to contribute acknowledge the level of risks associated to the Rogun Project as well as to check the analysis itself and, as far as possible, to get consensus about the mitigation measures and the way to implement them.

## 5.3 Statistics of the Risk Evaluation

Table 5-1 below shows the number of cases evaluated at each level of risk and how their gravity was reduced with the relevant mitigation measures.

Indeed, twelve cases had originally been evaluated at the two highest levels of risk, namely "extreme" and "major", and eleven were classified as being "moderate" risks. After proposal and application of mitigation measures, no case remained at the two highest levels of risk and only six of them remain at the level of "moderate" risks. Specific comments will be made on these cases.

Complementarily, Table 5-2 shows the location (Likelihood and Amount of Impact) of each Risk Case under study, before and after proposal and application of mitigation measures.

| | BEFORE MITIGATION | AFTER MITIGATION |
|---|---|---|
| | 6 | 0 |
| | 6 | 0 |
| | 11 | 6 |
| | 2 | 13 |
| | 1 | 7 |
| **Total** | 26 | 26 |

**Table 5-1: Risk distribution by severity level**
**Before and after mitigation measures**

| BEFORE MITIGATION | | | | | | |
|---|---|---|---|---|---|---|
| | | CONSEQUENCE (Amount in M.USD) | | | | |
| LIKELIHOOD | | Insignificant | Minor | Moderate | Major | Extreme |
| | | | 1 | 10 | 100 | 1 000 |
| Almost certain | 1 :1 | | | 6, 14 | 4B, 11 | 4A, 7, 17 |
| Likely | 9 :10 | | | 10A, 13, 21 | 16 | 2, 18, 20 |
| Moderate | 1 :10 | | | 5 | 15C, 19 | 8A, 12, 15B |
| Unlikely | 1 :100 | | | | | 1, 3, 8B, 10B |
| Rare | 1 :1 000 | | 15A | | | 9 |
| Extremely rare | 1 :10 000 | | | | | |

| AFTER MITIGATION | | | | | | |
|---|---|---|---|---|---|---|
| | | CONSEQUENCE (Amount in M.USD) | | | | |
| LIKELIHOOD | | Insignificant | Minor | Moderate | Major | Extreme |
| | | | 1 | 10 | 100 | 1 000 |
| Almost certain | 1 :1 | | 4B | 4A, 11 | | |
| Likely | 9 :10 | | 13, 14 | 7, 17 | | |
| Moderate | 1 :10 | | 6, 10A, 12 | 15C, 16, 18 | 15B | |
| Unlikely | 1 :100 | | 21 | 5 | 8B, 19 | 20 |
| Rare | 1 :1 000 | 9, 15A | | | | 1, 2, 3, 8A, 10B |
| Extremely rare | 1 :10 000 | | | | | |

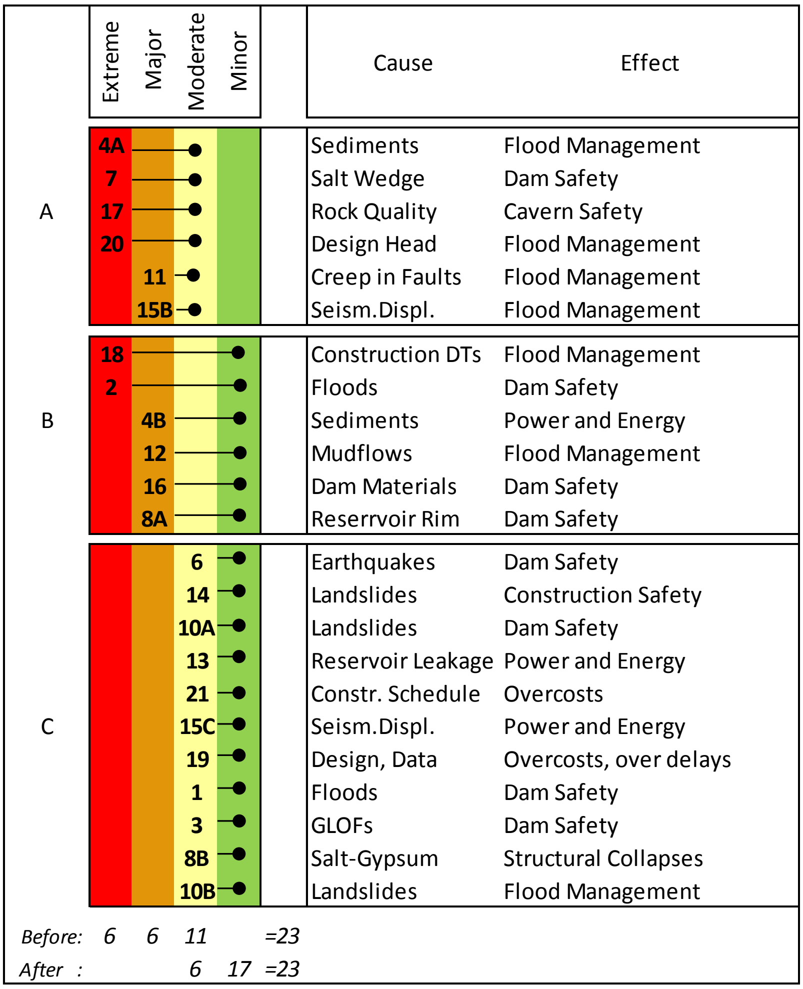
**Table 5-2: Risk I.D. per Level of Risk (Before and After Mitigation Measures)**

These tables have to be read together with the risk summary and risk sheets in Appendices.

## 5.4 Technical Analysis of Key Risks

Prior to the application of mitigation measures, 23 identified risks had a quotation higher or equal than “moderate”, 6 had been qualified as “extreme”, 6 as “major” and 11 as “moderate”, as shown in Figure 5-1.

After the planned mitigation measures, all the “extreme” and “major” risks have been reduced by one or two levels in gravity, leaving only six cases (group A) at a level of “moderate” risk.



|  | Extreme | Major | Moderate | Minor |  | Cause | Effect |
|---|---|---|---|---|---|---|---|
| A | 4A |  | ● |  |  | Sediments | Flood Management |
|  | 7 |  | ● |  |  | Salt Wedge | Dam Safety |
|  | 17 |  | ● |  |  | Rock Quality | Cavern Safety |
|  | 20 |  | ● |  |  | Design Head | Flood Management |
|  |  | 11 | ● |  |  | Creep in Faults | Flood Management |
|  |  | 15B | ● |  |  | Seism.Displ. | Flood Management |
| B | 18 |  |  | ● |  | Construction DTs | Flood Management |
|  | 2 |  |  | ● |  | Floods | Dam Safety |
|  |  | 4B |  | ● |  | Sediments | Power and Energy |
|  |  | 12 |  | ● |  | Mudflows | Flood Management |
|  |  | 16 |  | ● |  | Dam Materials | Dam Safety |
|  |  | 8A |  | ● |  | Reserrvoir Rim | Dam Safety |
| C |  |  | 6 | ● |  | Earthquakes | Dam Safety |
|  |  |  | 14 | ● |  | Landslides | Construction Safety |
|  |  |  | 10A | ● |  | Landslides | Dam Safety |
|  |  |  | 13 | ● |  | Reservoir Leakage | Power and Energy |
|  |  |  | 21 | ● |  | Constr. Schedule | Overcosts |
|  |  |  | 15C | ● |  | Seism.Displ. | Power and Energy |
|  |  |  | 19 | ● |  | Design, Data | Overcosts, over delays |
|  |  |  | 1 | ● |  | Floods | Dam Safety |
|  |  |  | 3 | ● |  | GLOFs | Dam Safety |
|  |  |  | 8B | ● |  | Salt-Gypsum | Structural Collapses |
|  |  |  | 10B | ● |  | Landslides | Flood Management |
| *Before:* | *6* | *6* | *11* |  | *=23* |  |  |
| *After :* |  |  | *6* | *17* | *=23* |  |  |

**Figure 5-1: Level of risks before and after mitigation measures**

The six cases in group “A” (reduced from “extreme” and “major” to “moderate”) do have causes closely related to the features that make of the Rogun Project a singular case: four natural causes (sediments, seismicity, active fault with salt in-filling, locally poor quality of rock) and one design cause-high hydraulic head upon gates in hydro-tunnels) which is closely related to the fact that the Rogun Dam is to become a world record in terms of height.

The six cases in group “A” are then characteristic of the Rogun Project. Their quotation may have still been reduced by one level, but it was strategically decided at this stage of the studies to leave them at the level of “moderate” for them to act as reminders of the natural and design singularities of the project. They are to recall that in the next project design stages (once when the most convenient project alternative will have been selected) further investigations and design improvements are to be developed. They are to be thoroughly discussed in a devoted Risk Workshop looking for consensus among all the parties and in order to acknowledge their significance in the development of the project.

Other risks (groups “B” and “C” in Figure 5-1) have been reduced to a level of “minor” risks.

The current risk analysis leads then to the conclusion that a few moderate risks remain, but that their qualification can still be improved in the next project stages. At this stage of the studies, all other risks have been reduced to a level of “minor” risks or less.

On the basis of the current technical risk analysis, the Rogun Hydropower Project may then continue its development and detailed design of the selected alternative can be reasonably envisaged.

Environmental, economic and financial as well as socio-political risks have not been evaluated in the present analysis which focuses mainly on the technical risks.

The following paragraphs conceptually describe the situation of each one of the six cases of risk belonging to group “A”. They are the highest quoted cases of risk, remaining at the level of “moderate” as reminders of the necessity of mitigation measures or the necessity of consensus. In all those cases the TEAS Consultant considers that they could have been classified at the level of “minor” risks but, once again, they are kept there as reminders of further investigations, developments or actions required.

**Sediments (risk case “4A”):**

The scarce vegetation and steep river slopes in the catchment area of the Vakhsh River facilitate the movement and transportation of large and abrasive granular material (sand, gravel and stones) along the river into the future reservoir.

In a few to several decades (depending upon the dam height alternative) the abrasive material will reach the intake of the hydro-tunnels devoted to flood evacuation putting the dam and the whole project in danger. As a consequence of this, a surface spillway has been added to the project at a high elevation in order to drastically prolong the safe useful life of the project.

This spillway, which increases the project cost, does not need to be installed with its full capacity at the very beginning of the project life. But without such a surface spillway the entire project is to be dismantled in a mid-term future or simply not constructed at all.

At its turn this spillway becomes a challenge in itself as it will become a world record in terms of falling head. Note that it must safely convey back to the river a large power flow. The power of a flow (discharge times head) may be potentially beneficial (flow through a powerhouse) or potentially detrimental (flow over a dam or along an unsafe waterway). In the case of the largest dam height alternative of Rogun that power may amount to as much as 24,000 MW (≈ 8,000 m3/s x 300 m).

Further investigations and studies are then to be conducted in the next project stages in order to improve the knowledge about sediments (characteristics and amount), to check and consolidate the proposed design for the surface spillway and to assess the opportunity when part and the totality of the surface spillway will be necessary.

**Active fault with salt in-filling (risk case “7”):**

The Ionaksh fault is an active, shallow rooted, regional thrust fault sub-vertically crossing the upstream part of the embankment dam. Besides its seismic potential (considered below when describing the risk case N° 15B) it has the singularity of its salt in-filling. That material, having a plastic behaviour, is pushed upwards as a salt wedge by the globally N-S regional state of compression. On the other hand the dissolution potential of salt in an aqueous environment will be activated by the creation of the reservoir, reducing the height of the salt wedge.

The upwards movement of the salt wedge is the opposite of the effect of salt dissolution. The current long term equilibrium of those two trends may be changed as the reservoir raises modifying water pressures gradients in the fault area in the vicinity of the dam.

Three possible cases can be envisaged:

- The current conditions of equilibrium between the two opposite trends prevail. In such a case the dam will not “notice” the presence of the salt wedge inside the Ionakhsh fault. This means that no additional risk is to be considered. The Ionakhsh fault can then be observed “only” as a source of seismic quakes and displacements. This aspect of the fault is considered separately.

- The upwards movement of the salt wedge prevails. In such a case the decametric plastic wedge could move into the base of the Stage-1 dam, a 130 m high embankment dam, at a rate of several millimetres or a few centimetres a year. This impact should not occur as the reservoir (particularly at its early stages) will increase the pressure gradients and consequently lead to the salt dissolution. And, should it occur, the consequences of the plastic wedge pushing against the embankment dam (more than 100 m in height) appear as negligible.

- The downwards movement of the salt wedge prevails. This happens only if the dissolution rate is higher than the ascending rate due to the compression of the salt wedge. The dissolution rate will first increase while the stage-1 dam and its grout curtain controls the flow along the foundation area. This situation should last as much as some ten years. Afterwards, when the main dam and its grouting curtain take the control water pressure gradient around the salt wedge will be drastically lowered because of the relative position of the grout curtain. This means that the dissolution rate falls down to values similar to those of the current condition of equilibrium.

The assessment studies have shown that if this situation prevails, decametric collapses could occur along the fault in the area of significant withdrawal of the salt wedge. If those collapses become continuous along the reach where the fault crosses the dam tail and if it makes the foundation to sink by more than some 25 m, the dam safety (particularly de dam core) could be affected at a significant level.

The available information on dissolution potential and on ascending rates of the salt wedge indicates that the chances for this situation to be reached, particularly in the short period of life of the Stage-1 dam, are negligible. In spite of that, monitoring and mitigation measures have been proposed to be put in place, to control and to follow up the water pressure gradients during the critical period. Further investigations have also been recommended for the next design stages, the goal being to have a complete view of the process involved.

Likelihood and consequences related to this situation have been kept at the level of “moderate” in order to underline an uncommon design feature of the Rogun H.P.P. and to recall the importance of the further investigations and studies. They are to confirm the appropriateness of the mitigation measures offering the due security to all the parties involved.

**Locally poor quality of rock (risk case “17”):**

Excavation of the powerhouse cavern started a couple of decades ago in a geological context of sandstones followed from West to East by siltstones. Convergence measurements have not yet shown stabilization of wall displacement, particularly in the siltstone area. Exceptionally large convergence was observed after works resumed in 2008.

Those measurements have put indeed into evidence that the installed rock support has not prevented rock mass distressing at a large scale, particularly in the area of weak of siltstones. Collapse or partial structural failure of the powerhouse cavern became a risk.

In this case of risk the causes are “almost certain”. If there would be collapse of the cavern, because of the repair cost and of the loss of gain, effects would amount to “major” or “extreme” in the established scale even if no lives are endangered.

Urgent monitoring and mitigating measures have already been proposed. According to the adopted scales of likelihood and impact this situation could have been considered as having a “minor” residual level of risk.

In spite of that it was decided to leave this situation among the few cases still representing a “moderate” risk in order to draw attention of the parties to the necessity of an urgent action.

**High hydraulic head upon gates in hydro-tunnels (risk case “20”):**

Flood management during construction, according to the existing design (HPI, 2010) is guaranteed with the help of tunnels DT-1, DT-2 and DT-3 for the lowest water levels and tunnels 3LO (3rd level operation tunnel) and ROP (remote operation tunnel). Their intakes are at the river level (DT-1 and DT-2), at El.1035 for DT-3 and at El.1145 for the two other.

In order to offer enough discharge capacity at every reservoir water surface elevation during construction several tunnels must operate at the same moment in case of flood and each tunnel must serve over a long range of heads. This will happen along a period of at least 15 years in order to cover a future reservoir depth of more than 300 m.

The adopted design heads are in all cases higher than 150 m and in the particular case of DT2 the maximum pressure on gates is slightly lower than 200 m.

The TEAS Consultant has considered these heads upon gates too risky. Indeed, high heads together with the high velocities operating on a permanent basis over several years without interruption are not considered compatible with the required level of safety. In the current conditions, if only one single tunnel gets out of service the full project will be in danger.

In order to avoid that situation the TEAS Consultant requires that a maximum head on gates of 120 m is adopted and that flow velocity is limited accordingly. But this design criterion “mathematically” increases the number of tunnels necessary to safely pass floods during construction.

Under the new design condition risks are significantly lower, but there are not statistics to measure or estimate the original and the residual risks. On the other hand, even if the cost of the mitigation measure (two additional tunnels in the case of the highest dam alternative) is not significant with respect to the total direct cost of the project, criticism arose about this mitigation measure from the side of concerned parties.

For those reasons this risk case has been conserved as a “moderate” risk in order to further work on it looking for a consensus among the parties.

**Creep in faults affecting hydraulic tunnels (risk case “11”):**

Besides the intense, sudden movements occurring along faults during earthquakes also long term, “nearly” continuous (creep) movements occur along faults as the result of afterwards block accommodation. The 1970-80s measurement campaigns detected creeping rates of about 3 mm/year for the Ionaksh fault and about 2.3 mm/year of vertical component for the Fault N°35.

When those relative movements occur (independently of any immediate earthquake) they may impact by deformation the dam foundation; they may produce a progressive inclination of turbines axis and may also damage the hydraulic tunnel linings where tunnels cross those faults.

The dam core location has been selected as to avoid creeping faults. Besides it, embankment dams are well suited to accommodate those deformations (0.3 m in 100 years). Additionally key organs as filters and transitions have been enlarged to better contribute to absorb relative movements. Tilting of turbines axis may compensated by mechanical readjusting of the axis when cumulated deformations require it. Tunnels crossing creeping faults may then be the project components more sensitive to this natural cause.

Indeed, even the rigid lining of tunnels is unable to withstand cumulated large shear efforts. If they happen and the tunnel axis suffers differential displacements, additional head losses will occur, cavitation risks will appear and (if water leaks through sheared sections) tunnel undermining may occur. This latter case appears as the physically most critical condition.

Temporary tunnels for flood management during construction will operate during a limited period of time (always shorter than 10 years). Consequences may then not be significant but, in any case, mitigation design measures have been implemented for permanent as well as for temporary tunnels. They consist of section enlargement together with deep sealing of fault areas or (for smaller sections) linings allowing for a certain level of deformations but devised to avoid leaking.

In all the cases (for dam foundation, for turbine axis as well as for tunnels crossing creeping faults) a complementary measurement campaign is to be implemented and a follow up monitoring system is to be set up.

**Seismicity (risk case “15B”):**

The Rogun Hydropower Project is located in a complex sismo-tectonic context where active faults have been identified with significant quaking and shearing potential.

The dam itself is located in the tectonic block between the Ionaksh and the Gulizindan faults, two regional thrust faults. The current seismic assessment estimates co-seismic displacements in the order of magnitude of 1 m along these faults, concomitant to the MCE (maximum credible earthquake). Local faults accommodating the block deformation could, under similar conditions, experience co-seismic displacements in the order of magnitude of 0.1 m to 0.2 m.

The upstream tail of the dam itself is located upon the Ionaksh fault, but also the Diversion Tunnel N° 3 and the Mid-level Outlet N°1 cross this feature in their upstream portions. These 15 m diameter tunnels contribute to the flood management during construction. Their role in preserving the dam safety is important. The likelihood of such events (associated to the MCE) is reduced and the period of exposure (construction period) is also short. But the consequences could be important in case of occurrence.

Mitigation measures have been envisaged (section enlargement and reinforcement together with an additional upstream set of gates to allow for control and repair works). It represents an additional cost but it is considered a necessity in order to reduce the risk to acceptable limits.

At future project stages the refinement estimate of the co-seismic displacements evaluation is to be re-evaluated and the technical solutions are to be refined for execution purposes.

# 6 CONCLUSIONS

The current Risk Analysis has been performed as the closure of Phase-II of the Techno-Economical Assessment Studies of the Rogun Project, as developed so far.

The present report describes the risk identification procedures as well as the risk evaluation methods and ranges, proposes mitigation measures after which residual risks are re-evaluated. Dedicated Risk Sheets have been elaborated for each one of the 26 cases of risk considered in this study.

Only six cases remain at the level of “moderate” risks after application of the proposed mitigation measures; none remains at higher levels. Their quotation may have still been reduced by one level, but it was strategically decided to leave them at the level of “moderate” for them to act as reminders of the natural and design singularities of the project. They are to recall that in the next project stages (once when the most convenient project alternative will have been selected) further investigations and design improvements are to be developed. They are to be thoroughly discussed in the Risk Workshop looking for consensus among all the parties and in order to acknowledge their significance in the development of the project.

The sources of those six remaining risks are five natural causes (sediments, seismicity, active fault with salt in-filling, locally poor quality of rock, creep in faults) and one design cause (too a high hydraulic head upon gates in hydro-tunnels) which is closely related to the fact that the Rogun Dam is to become a world record in terms of height. These five risk cases are then to be considered as representative of the project complexity and difficulty.

Environmental, economic and financial as well as socio-political risks have not been evaluated in this analysis.

On the basis of these conclusions of the current technical risk analysis, the Rogun Hydropower Project may then continue its development for the next step of the studies, that is to say detailed design of the selected alternative.

Further investigations and design refinements are to be performed in the next project stages, once when the dam height alternative will have been chosen.

# 7 APPENDICES

## 7.1 Interaction Matrix

# Risk Analysis - Interaction Matrix

| | | | Systems and Sub-systems that can be impacted upon | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Families of causes able to affect parts of the project | | EFFECTS<br>CAUSES | Dam system | | | | Construction site | | | Reservoir system | | | | Access | | Flood management system | | | | Power & Energy system | | | | | | | | | | | | |
| | | | Pre-cofferdam | Cofferdam | Stage 1 dam | Main dam | Workers accomodations | Site equipments | Site plants | Reservoir rim | Rogun city | Karstic structures | Gulzidan fault area | Construction access | Permanent access | Diversion Tunnels 1,2,3 | Mid Level tunnels 1,(2) | High level Tunnels 1, (2), (3) | Surface spillway | Generator | Transformers | Cable galleries | Switchyard | Transmission lines | Intake | Waterways | Penstock | Powerhouse | Turbines | Draft tube | Tailrace | Energy production |
| Natural | Hydrology | Water availability | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| | | Sediments | | | | | | | | | | | | | | X | X | X | X | | | | | | X | X | X | | X | X | | |
| | | Construction floods | | X | X | X | | | | | | | | | | Δ | Δ | Δ | Δ | | | | | | | | | | | | | |
| | | Rare floods | | | X | X | | | | | | | | | | Δ | Δ | Δ | Δ | | | | | | | | | | | | | |
| | | GLOFs | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Geology / Geotechnics / Geomechanics | Salt dissolution in dam foundation | | | | X | | | | | | | | | | X | X | X | | | | | | | X | | | | | | | |
| | | Salt intrusion in RB | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | RB-DS important instability | | | X | X | Δ | Δ | Δ | | | | | | | X | X | X | X | | | | | | | | | | | | | |
| | | Long-term creeping of faults | | X | X | X | | | | | | | | | | X | X | | | | | | | | | | X | X | | | | |
| | | Mudflows from Obishur R. and other streams | | X | X | | | | | | | | | | X | X | | | | | | | | | | | | | | | X | |
| | | Leakage from reservoir | | | | | | | | X | | X | X | | | | | | | | | | | | | | | X | | | | |
| | | Co-sismic displacements | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Reservoir rim slope instability | | X | X | X | Δ | Δ | Δ | X | X | | | | X | Δ | Δ | Δ | Δ | | | | | | | | | | | | | |
| | | Dam material: inappropriate survey, inadequate material | X | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Structures-Caverns: rock excavation | | | Δ | Δ | | | | | | | | | | | | | | Δ | X | | | | | | | X | | | | Δ |
| | | Co-sismic displacements | | | X | X | | | | | | | | | | X | X | X | X | | X | | | | | | | X | | | | X |
| | | Dam excavation: slope instabilities | | | X | X | Δ | Δ | Δ | | | | | | | | | | | | | | | | | | | | | | | |
| | Tectonics-Seismicity | Earthquakes | | | X | X | | | | | | | | | | X | X | X | X | | | | | | | | | | | | | |
| | Weather | Temperature | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rain | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Snow | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Ice | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Technical | Design | Evaluation of natural conditions | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Design studies | X | X | X | X | | | | | | | | | | X | X | X | X | | | | | | | | | | | | | |
| | | Maximum head in tunnels | X | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Construction | Diversion/Tailrace tunnels: construction quality | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | X | |
| | | Construction experience and technics. Equipment | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Construction schedule | X | X | X | X | | | | | | | | | | X | X | X | X | | | | | | | | | | | | | |
| | | Contractual issues | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Fabrication | Fabrication technics, materials, schedule | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Contractual issues | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Maintenance & Operation | Maintenance: Experience of personnel. Schedule and planning | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Operation: Experience of personnel. Schedule and planning | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Monitoring programs | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Decommissioning | Opportuniy - Procedures | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Economico-Financial | Market prices | Materials and equipment: Present and future conditions. Availability. Inflation. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Energy demand | Mid- and long term changes in demand | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Funding | Availability of funds. Rates. Insurances. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Socio-Political | Social | Restlement conditions | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Political at National level | Taxation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Political decisions | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Political Regional level | Poor plan for shared resources | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Reservoir operation / filling not agreed | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Main systems impacted (related to the risk sheets) are indicated with a red cross.
Others systems could be impacted and are indicated with a blue triangle.

## 7.2 Risk summary and risk sheets

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| | Cause | | | System(s) | Risk evaluation | |
|---|---|---|---|---|---|---|
| Sheet n° | Level 1 | Level 2 | Level 3 | | Before mitigation | After mitigation |
| 1 | Natural | Hydrology | Rare floods | Dam system | 🟨 | 🟩 |
| 2 | Natural | Hydrology | Construction floods | Dam system | 🟥 | 🟩 |
| 3 | Natural | Hydrology | GLOFs | Dam system | 🟨 | 🟩 |
| 4A | Natural | Hydrology | Sediments | Flood management system | 🟥 | 🟨 |
| 4B | Natural | Hydrology | Sediments | Power & Energy system | 🟧 | 🟩 |
| 5 | Natural | Hydrology | Water availability | Power & Energy system | 🟩 | 🟩 |
| 6 | Natural | Seismic | Earthquakes | Dam system / Flood management system | 🟨 | 🟩 |
| 7 | Natural | Geological / Geotechnical / Geomechanical | Salt dissolution in dam foundation | Dam system / Flood management system | 🟥 | 🟨 |
| 8A | Natural | Geology / Geotechnics / Geomechanics | Reservoir rim slope instability | Dam System /Access | 🟧 | 🟩 |
| 8B | Natural | Geological / Geotechnical / Geomechanical | Karst in the reservoir (close to Rogun city) | Reservoir system | 🟨 | 🟩 |
| 9 | Natural | Geology / Geotechnics / Geomechanics | Salt intrusion in RB | Dam system | 🟩 | 🟩 |
| 10A | Natural | Geology / Geotechnics / Geomechanics | RB-DS important instability | Dam system / Flood management system | 🟨 | 🟩 |
| 10B | Natural | Geology / Geotechnics / Geomechanics | RB-DS important instability | Dam system | 🟨 | 🟩 |
| 11 | Natural | Geology / Geotechnics / Geomechanics | Long-term creeping of faults | Dam system / Flood management system / Power & Energy system | 🟧 | 🟨 |
| 12 | Natural | Geology / Geotechnics / Geomechanics | Mudflows from Obishur R. and other streams | Access / Dam system / Flood management system / Power & Energy system | 🟧 | 🟩 |
| 13 | Natural | Geology / Geotechnics / Geomechanics | Leakage from reservoir | Reservoir system / Power & Energy system | 🟨 | 🟩 |
| 14 | Natural | Geology / Geotechnics / Geomechanics | Dam excavations slope instabilities | Dam system | 🟨 | 🟩 |
| 15A | Natural | Geology / Geotechnics / Geomechanics | Co-sismic displacements | Dam system | 🟩 | 🟩 |
| 15B | Natural | Geology / Geotechnics / Geomechanics | Co-sismic displacements | Flood management system | 🟧 | 🟨 |
| 15C | Natural | Geology / Geotechnics / Geomechanics | Co-sismic displacements | Power & Energy system | 🟨 | 🟩 |
| 16 | Natural | Geology / Geotechnics / Geomechanics | Dam materials: Inappropriate survey, inadequate materials | Dam system | 🟧 | 🟩 |
| 17 | Natural | Geology / Geotechnics / Geomechanics | Structures-Caverns: rock excavation | Power & Energy system | 🟥 | 🟨 |
| 18 | Technical | Maintenance & Operation | Diversion/Tailerace tunnels: construction quality | Flood management system / Power & Energy system | 🟥 | 🟩 |
| 19 | Technical | Design | Design studies | Dam system/Flood management system | 🟨 | 🟩 |
| 20 | Technical | Design | Maximum head in tunnels | Dam system | 🟥 | 🟨 |
| 21 | Technical | Construction | Construction schedule | Dam system/Flood management system | 🟨 | 🟩 |

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| | |
|---|---|
| **Sheet n°** | 1 |
| **Risk ID** | Rare floods<br>Dam system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

**IDENTIFICATION**

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Hydrology |
| **Level 3** | Rare floods |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Main dam |
| | Dam system | Stage 1 dam |
| | | |
| | | |
| | | |

**DESCRIPTION (before mitigation)**

| **CAUSE (S)** | **Likelihood** |
|---|---|
| 1. Insufficient design of discharge organs / Weakness in maintenance and operation. | Unlikely |

**Comments**

a. On the long term, climate change impact induces an increase of flood.

b. A wrong evaluation due to hydrology studies can induced an overflooding of the dam.

| **IMPACT (S)** | **Evaluation** |
|---|---|
| 1. Dam collapse by overtopping flows. | Extreme |

**Comments**

a. An underestimated flood probably causes a flow over dam crest. For an embankment dam, such a flow leads to a dam collapse.

b. A poor maintenance of flood managment organs could causes a reduction of evacuation capacity. A small overtopping is possible in that case.

| | **Risk** |
|---|---|
| | 🟨 |
| **ADOPTED** | 🟨 |

**MITIGATION MEASURES**

**Recommended mitigation measures**

1. State of the art evolution techniques and forecast climate change consideration.
/ Adapted design techniques (Surface spillway).

/ Hydromechanical materials maintenance and regular gates opening/closing tests.

Natur

**Comments**

a. A monitoring program is to be defined in order to inspect, test and regular servicing of hydromechanical equipments

**Recommended mitigation measures**

1. An emergency plan shall be applied and allows to evacuate most of the downstream populations concerned by the dam collapse.

**Comments**

**RESIDUAL RISK (after mitigation)**

| **CAUSE (S)** | **Likelihood** |
|---|---|
| 1. Insufficient design of discharge organs / Weakness in maintenance and operation. | Rare |

**Comments**

| **IMPACT (S)** | **Evaluation** |
|---|---|
| 1. Dam collapse by overtopping flows. | Extreme |

**Comments**

a. Despite the evacuation of the most possible downstream populations, the consequences of a dam collapse remains catastrophic.

| | **Risk** |
|---|---|
| | 🟩 |
| **ADOPTED** | 🟩 |

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| | |
|---|---|
| **Sheet n°** | 2 |
| **Risk ID** | Construction floods<br>Dam system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟥 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Hydrology |
| **Level 3** | Construction floods |

**IMPACT**

| | **SYSTEM (S)** | **COMPONENT (S)** |
|---|---|---|
| **1.** | Dam system | Main dam |
| **2.** | Dam system | Stage 1 dam |
| **3.** | Dam system | Cofferdam |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Main dam: construction delay.** | Likely |
| **2. Stage 1: construction delay.** | Likely |
| **3. Cofferdam: construction delay.** | Likely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Main dam collapse.** | Extreme |
| **2. Stage 1 dam collapse.** | Extreme |
| **3. Cofferdam collapse.** | Moderate |

| | **Risk** |
|---|---|
| | 🟥 |
| | 🟥 |
| | 🟨 |
| **ADOPTED** | 🟥 |

**Comments**

**a. A wrong evauluation due to hydrology studies or insufficient design of discharge period of discharge organs can induce an extreme impact for main dam and stage 1 dam, but with an extremely rare probability.**

**Comments**

**a. A poor maintenance of flood managment organs could cause a reduction of evacuation capacity. Overtopping is possible in that case.**

## MITIGATION MEASURES

**Recommended mitigation measures**

Natur

**1 - 2 - 3. State of the arts techniques.**

**/ Maintenance and operation contract.**

**/ Make sure to respect the construction schedule (financing, neighboorhing countries agreement, ...)**

**Comments**

**Recommended mitigation measures**

**1 - 2 - 3. An emergency plan shall be applied to allow evacuating most of the downstream populations concerned by the dam collapse.**

**/ Delay the river diversion if necessary.**

**Comments**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Main dam: construction delay.** | Rare |
| **2. Stage 1: construction delay.** | Rare |
| **3. Cofferdam: construction delay.** | Rare |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Main dam collapse.** | Extreme |
| **2. Stage 1 dam collapse.** | Extreme |
| **3. Cofferdam collapse.** | Moderate |

| | **Risk** |
|---|---|
| | 🟩 |
| | 🟩 |
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**a. The consultant underlines the necessity to respect the schedules, and then the construction period.**

**Comments**

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| | |
|---|---|
| **Sheet n°** | 3 |
| **Risk ID** | GLOFs<br>Dam system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Hydrology |
| **Level 3** | GLOFs |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Main dam |
| | | |
| | | |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Wrong evaluation of the GLOFs potential.** | Unlikely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Dam collapse.** | Extreme |

| | **Risk** |
|---|---|
| | 🟨 |
| **ADOPTED** | 🟨 |

**Comments**

**Comments**

## MITIGATION MEASURES

**Recommended mitigation measures**

**1. Glacier inventory and study.**
**/ Surveillance of glaciers.**
**/ Adequate freeboards.**

**Recommended mitigation measures**

**1. An emergency plan shall be applied and allows to evacuate most of the downstream populations concerned by the dam collapse.**

Natur

**Comments**

**Comments**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Wrong evaluation due to hydrology studies.** | Rare |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Dam collapse.** | Extreme |

| | **Risk** |
|---|---|
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**Comments**

**a. Despite the evacuation of the most possible downstream populations, the consequences of a dam collapse remains catastrophic.**

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| **Sheet n°** | 4A |
|---|---|
| **Risk ID** | Sediments<br>Flood management system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟥 | 🟨 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Hydrology |
| **Level 3** | Sediments |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Flood management system | Temporary low tunnels |
| 2 | Flood management system | Temporary high tunnels |
| 3 | Flood management system | Permanent tunnels |
| 4 | Flood management system | Surface Spillways |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Sediment through temporary low tunnels.** | Almost certain |
| **2. Sediment through temporary high tunnels.** | Rare |
| **3. Sediment through permanent tunnels.** | Almost certain |
| **4. Sediment through permanent surface spillways.** | Almost certain |

| **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|
| **1. Abrasion damages of temporary low tunnels.** | Extreme | 🟥 |
| **2. Abrasion damages of temporary high tunnels.** | Major | 🟩 |
| **3. Abrasion damages of permanent tunnnels.** | Extreme | 🟥 |
| **4. Abrasion damages of surface spillways.** | Extreme | 🟥 |
| | **ADOPTED** | 🟥 |

**Comments**

**a. No trap efficiency of the early stage low reservoir, therefore abrasive materials through the low tunnels.**

**b. In the short time available, no sediments will have reached the high tunnels.**

**Comments**

## MITIGATION MEASURES

**Recommended mitigation measures**

Natur

**1. Proper design. Low velocities. Allowing inspection and maintenance works.**

**3. Do not rely on pressure tunnels for long term flood managment.**

**4. Redundancy of the spillway facilities.**

**1 - 2 - 3 - 4. Monitoring flow turbidity and closure of tunnels when abrasive materials reach the intakes.**

**/ Recurrent preventive maintenance.**

**Recommended mitigation measures**

**1 - 2. End of life design considerations.**

**1 - 2- 3. Closure of tunnels when abrasive materials reach the intakes.**

**1 - 2 - 3 - 4. Repair works after each flood season.**

**Comments**

**Comments**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Sediment through temporary low tunnels.** | Likely |
| **2. Sediment through temporary high tunnels.** | Rare |
| **3. Sediment through permanent tunnels.** | Extremely rare |
| **4. Sediment through permanent surface spillways.** | Almost certain |

| **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|
| **1. Abrasion damages of temporary low tunnels.** | Moderate | 🟨 |
| **2. Abrasion damages of temporary high tunnels.** | Moderate | 🟩 |
| **3. Abrasion damages of permanent tunnnels.** | Insignificant | 🟩 |
| **4. Abrasion damages of surface spillways.** | Moderate | 🟨 |
| | **ADOPTED** | 🟨 |

**Comments**

**Comments**

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|---|---|---|

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|---|---|
| **Sheet n°** | 4B |
| **Risk ID** | Sediments<br>Power & Energy system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟧 | 🟩 |

**IDENTIFICATION**

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Hydrology |
| **Level 3** | Sediments |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Power & Energy system | Intake |
| 2 | Power & Energy system | Waterways |
| 3 | Power & Energy system | Turbines |
| | | |
| | | |

**DESCRIPTION (before mitigation)**

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Silting up of the power tunnel intake.** | Almost certain |
| **2. Sediment through waterways.** | Almost certain |
| **3. Sediment through turbines** | Almost certain |

| **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|
| **1. Loss of efficiency of power tunnel intake.** | Moderate | 🟨 |
| **2. Loss of efficiency of waterways.** | Minor | 🟩 |
| **3. Excessive abrasion of turbines** | Major | 🟧 |
| | **ADOPTED** | 🟧 |

**Comments**

**Comments**

**1-2-3. A loss of efficiency or an excessive abrasion can induce a loss of energy production.**

**MITIGATION MEASURES**

**Recommended mitigation measures**

Natural

**Comments**

**Recommended mitigation measures**

**1. Additional structure at higher level.**

**3. Runners change / Repair works: metal reconstitution.**

**Comments**

**RESIDUAL RISK (after mitigation)**

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Silting up of the power tunnel intake.** | Almost certain |
| **2. Sediment through waterways.** | Almost certain |
| **3. Sediment through turbines.** | Almost certain |

| **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|
| **1. Loss of efficiency of power tunnel intake.** | Insignificant | 🟩 |
| **2. Loss of efficiency of waterways.** | Minor | 🟩 |
| **3. Excessive abrasion of turbines.** | Minor | 🟩 |
| | **ADOPTED** | 🟩 |

**Comments**

**Comments**

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|---|---|
| **Sheet n°** | 5 |
| **Risk ID** | Water availability<br>Power & Energy system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟩 | 🟩 |

IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Hydrology |
| **Level 3** | Water availability |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Power & Energy system | Energy production |
| | | |
| | | |
| | | |
| | | |

DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Wrong evaluation of river inflows.** | Moderate |

| **Comments** |
|---|
| |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Loss of energy production.** | Moderate |

| **Comments** |
|---|
| |

| | **Risk** |
|---|---|
| | 🟩 |
| **ADOPTED** | 🟩 |

MITIGATION MEASURES

| **Recommended mitigation measures** |
|---|
| **a. Inflows analysis should be rigorous and based on international practices. Historical measured data should be considered.**<br>**b. Exhaustive utilization of hydrographical ganging station as well as historical data from Nurek.** |

Natur

| **Comments** |
|---|
| |

| **Recommended mitigation measures** |
|---|
| |

| **Comments** |
|---|
| |

RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Wrong evaluation of river inflows.** | Unlikely |

| **Comments** |
|---|
| |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Loss of energy production.** | Moderate |

| **Comments** |
|---|
| |

| | **Risk** |
|---|---|
| | 🟩 |
| **ADOPTED** | 🟩 |

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| | |
|---|---|
| **Sheet n°** | 6 |
| **Risk ID** | Earthquakes<br>Dam system / Flood management system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Seismic |
| **Level 3** | Earthquakes |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1, 2, 3 | Dam system | Main dam |
| | Dam system | Stage 1 dam |
| | Flood management system | Tunnels |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Large earthquake (MCE).** | Rare |
| **2. Large earthquake (OBE).** | Moderate |
| **3. Reservoir triggered seismicity.** | Almost certain |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Damage to the dam and other structures.** | Extreme |
| **2. Loss of energy production.** | Moderate |
| **3. Damage to the structures.** | Moderate |

| | **Risk** |
|---|---|
| | 🟩 |
| | 🟩 |
| | 🟨 |
| **ADOPTED** | 🟨 |

**Comments**

**Comments**

## MITIGATION MEASURES

**Recommended mitigation measures**

**3. Appropriate rate of reservoir filling.**

**Recommended mitigation measures**

**1. Design earthquake of the dam for the MCE, safe design for all structures.**

**2. State of the art design and engineering at the level of OBE.**

**3. Monitoring of reservoir induced seismicity before and during impounding.**

Natural

**Comments**

**Comments**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Large earthquake (MCE).** | Rare |
| **2. Large earthquake (OBE).** | Moderate |
| **3. Reservoir triggered seismicity.** | Moderate |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Damage to the dam and other structures.** | Minor |
| **2. Loss of energy production.** | Insignificant |
| **3. Damage to the structures.** | Minor |

| | **Risk** |
|---|---|
| | 🟩 |
| | 🟩 |
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**Comments**

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|---|---|
| **Sheet n°** | 7 |
| **Risk ID** | Salt dissolution in dam foundation<br>Dam system / Flood management system |

| Risk evaluation | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟥 | 🟨 |

## IDENTIFICATION

| CAUSE | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geological / Geotechnical / Geomechanical |
| **Level 3** | Salt dissolution in dam foundation |

| IMPACT | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Main dam |
| 2 | Power & Energy system | Intake |
| 3. | Flood management system | Diversion Tunnels 1,2,3 |
| 4. | Flood management system | Mid Level tunnels 1,(2) |
| | Flood management system | High level Tunnels 1, (2), (3) |
| | | |

## DESCRIPTION (before mitigation)

| CAUSE (S) | Likelihood |
|---|---|
| 1. Leaching of salt wedge within Ionakhsh fault. | Almost certain |
| 2. Leaching of salt within the left bank. | Moderate |
| 3. Leaching of salt within the left bank. | Moderate |
| 4. Leaching of salt within the left bank. | Moderate |

| IMPACT (S) | Evaluation | Risk |
|---|---|---|
| 1. Deformation of foundation and dam body. | Extreme | 🟥 |
| 2. Creeping or sliding of power intake foundations. | Major | 🟨 |
| 3. Damages to portals of diversion tunnels 1, 2. Damage to diversion tunnel 3. | Major | 🟨 |
| 4. Potential damage to mid-level outlet or high-level outlets. | Extreme | 🟧 |
| | **ADOPTED** | 🟥 |

**Comments**

a. Excessive leaching of the salt wedge of Ionakhsh Fault: the top of the salt wedge get lower.
b. Salt elevation and arrangement within the right bank is not known, possible dissolution after impounding of such salt is deemed not impossible.

**Comments**

a. If the rate of leaching is larger than expected, the deformation of the stage 1 dam body and foundation may lead, in the extreme case, to overtopping. In case of the main dam, it may affect watertightness components of the dam (clay core), and may finally lead to overtopping.
b. Dissolution of the salt wedge at the foot of the slope, which constitutes the intake foundation may lead to unacceptable creeping even sliding of the intake foundation (major consequences, since flood management still assumed to be in working conditions).
c.Rapid leaching of salt may lead to unacceptable settlements of portal foundations, and collapse due to scouring.
d. Damages to the mid-level outlet and other tunnels may lead to deformation of tunnel lining, having catastrophic consequences if unnoticed and leading to tunnel collapse after scouring by water under high velocity.

Natural

## MITIGATION MEASURES

**Recommended mitigation measures**

1 -2-3-4. Implementation of hydraulic barrier
/ Grouting of the top area of the salt wedge (<1 LU)
/ Monitoring of salt wedge rising rate
/ General monitoring (salt content, gravimetry, deformations, etc.)
/ Grouting of Gulizindan Fault end and right bank investigation.

**Recommended mitigation measures**

1 -2-3-4. Reduction of gradient above top of salt wedge
/ Reduction of water circulation above the top of salt wedge
/ Calibration of leaching model for better assessment of leaching
/ Survey of eventual leaching progression
/ Check potential leakages through right bank or Gulizindan Fault.

**Comments**

a. Hydraulic barrier downstream the top of the salt wedge is to be provided, with pressure being that of the reservoir to balance the gradient.
b. The grouting of the top area of the salt wedge shall be efficiently performed and actually reach less than 1 LU in hydraulic conductivity
c. Monitoring of the rising rate of the salt wedge is to performed, as an essential input data for modelling of the leaching process.
d. General monitoring as per Phase 0 report RP38 is to be implemented (measurements of settlements, salinity of water, investigation of the possible evolution in voids by microgravimetry, etc.)
e. Detailed geological investigations to check the exact elevation of salt within the downstream right bank are to be performed.

**Comments**

a. Both hydraulic barriers and grouting of the top area of the salt wedge are judged necessary from the modelling of salt leaching, at least for stage 1 dam.
b. The rising rate of the salt wedge within the Ionakhsh Fault is a key input parameter for salt leaching modelling and needs to be verified as soon as possible.
c. All other monitoring listed in RP38 report aims at following the progress of the potential dissolution of the salt wedge, by measuring settlements, water salinity variations and regular microgravimetric investigations.
d. Investigations of the right bank should allow to know if specific mitigation measures are still required.

## RESIDUAL RISK (after mitigation)

| CAUSE (S) | Likelihood |
|---|---|
| 1. Leaching of salt wedge within Ionakhsh fault. | Likely |
| 2. Leaching of salt within the right bank. | Unlikely |
| 3. Leaching of salt within the right bank. | Unlikely |
| 4. Leaching of salt within the right bank. | Unlikely |

| IMPACT (S) | Evaluation | Risk |
|---|---|---|
| 1. Deformation of foundation and dam body (stage 1, main dam). | Moderate | 🟨 |
| 2. Creeping or sliding of power intake foundations. | Moderate | 🟩 |
| 3. Damages to portals of diversion tunnels 1, 2 . Damage to tunnel 3. | Moderate | 🟩 |
| 4. Potential damage to mid-level outlet or high-level outlets. | Moderate | 🟩 |
| | **ADOPTED** | 🟨 |

**Comments**

a. The likelihood of reduction of efficiency of the hydraulic barrier will straightly depend upon its correct desing and implementation during construction. It makes reference to excessive leaching.
b. The loss of efficiency at long term of the grouting is unavoidable, due to the progressive creepinf of the Ionakhsh Fault, and may be completely inefficient in case of co-sismic movement along this fault.
c. Monitoring devices shall be selected and installed with care, in order to guarantee long-term service, within salty water.

**Comments**

a. The hydraulic barrier is mostly necessary for the stage 1 dam.
b. It is verified that loss of efficiency of grouting down to 0.1LU does not have any impact, according to salt leaching model; like hydraulic barrier, it is not really necessary for the main dam.
c. Having the monitoring means failing to work, especially for stage 1 dam results in that any leaching will occur unnoticed, and damages can appear suddenly; risk is major for the stage 1 dam.
d. It is supposed for the residual risk that dedicated investigations were carried out, such as the conditions of right bank are better known than today.

## GENERAL INFORMATION

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| | |
|---|---|
| **Sheet n°** | 8A |
| **Risk ID** | Reservoir rim slope instability<br>Dam System /Access |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟧 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Reservoir rim slope instability |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1 | Dam system | Main dam |
| | Dam system | Stage 1 dam |
| | Dam system | Cofferdam |
| 2 | Access | Permanent access |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Major landslide in the reservoir.** | Moderate |
| **2. Minor landslides or rock falls in the reservoir.** | Almost certain |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Overtopping of the dam.** | Extreme |
| **2. Damages to access roads.** | Minor |

| | **Risk** |
|---|---|
| | 🟧 |
| | 🟩 |
| **ADOPTED** | 🟧 |

**Comments**

**a. Occurrence of large volume landslide in the reservoir, during impounding or normal operation (fluctuations of the reservoir, rainy episodes, earthquakes).**
**b. Occurrence of minor landslides or rockfalls in the reservoir, with volume and position such that overtopping of the dam is not feared.**
**c. Occurence of major mudflows or debris flows in streams entering the reservoir during rainy episodes or as a consequence of the breach of landslide dam.**

**d. Higher rate of dissolution is certain, but the amount of dissolution is unknown. The likelihood of occurrence of landslide > 100 Mm3 is very low. It would result from failure of the slope as sudden adjustment to dissolution of considerable evaporite rock masses at the toe of the slope, over a section of km long.**

**g. Others minor/moderate causes with minor impact are identified: mudflows / Karts / Water elevation (loss of cohesion).**

**f. For Stage 1 dam, a minor probability is considered because of the short life span and reservoir elevation.**

**Comments**

**a. Possible overtopping of the dam by the wave generated by the impact of the sliding mass into the reservoir: probability of overtopping to occur depending upon landslide volume and proximity to the dam.**

**b. The likelihood of occurrence of landslide > 100 Mm3 is low. It would result from failure of the slope as sudden adjustment to dissolution of considerable evaporite rock masses at the toe of the slope.**

**c. In this case, the main damages to be feared are those to dwellings and access roads along the reservoir.**
**d. Occurence of major mudflow (e.g. large mudflow in Passimurakho Valley).**

## MITIGATION MEASURES

**Recommended mitigation measures**

Natur

**1 - 2. Monitoring of potentially unstable reservoir slopes.**
**/ Freeboard allowance during dam operation.**

**/ Appropriate filling rate of reservoir.**

**/ Restrictions over rate of variation of reservoir level during operation.**

**/ Dismantelling early.**

**Recommended mitigation measures**

**1 - 2 Interpretation of monitoring data to inform about possible slope failures.**
**/ To avoid rapid unloading of toe of potentially unstable masses.**

**/ To avoid rapid variations of pore pressure in potentially unstable masses.**

**/ Reduce reservoir level if monitoring data show high risk, in order to avoir an overtopping.**

**Comments**

**a. Potentially unstable masses of large volume, susceptible to trigger a wave which would overtop the dam, are to be monitored, before starting impounding.**
**b. An adequate freeboard shall be maintained between reservoir level and crest of the dam, according possible amplitude of wave generated by a large landslide or mudflow (monitoring).**
**c. The filling rate of the reservoir is to be adapted to avoid slope failures, with simultaneous checking of monitoring data.**
**d. Rates of variations of the reservoir level are to be adapted in the same way as the filling rate, checking monitoring data.**

**Comments**

**a. Displacements, rate and acceleration of movements among others shall be followed very closely and allow reaction in case a failure is suspected to occur.**
**b. An adequate freeboard in case of suspicion of landslide occurrence will prevent overtoping of the dam.**
**c. Control of pore pressures within potentially unstable masses.**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Major landslide in the reservoir.** | Rare |
| **2. Minor landslides or rock falls in the reservoir.** | Moderate |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Overtopping of the dam.** | Extreme |
| **2. Damages to access roads.** | Minor |

| | **Risk** |
|---|---|
| | 🟩 |
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**a. Failure of a large volume of material may remain unpredictable with only monitoring, in case of earthquake-triggered landslide or if the landslide has not been monitored because not considered as dangerous.**
**b. If the event has not been anticipated in its real extent, freeboard can reveal insufficient**
**c. If monitoring data are not treated and interpreted in due time, prediction of any failure event will not be possible**

**Comments**

**a. Overtopping of dam in case of occurrence of such unpredicted event**
**b. Temporary overtopping only if freeboard insufficient; failure of dam may not occur.**
**c. Without monitoring, prediction of any event is impossible.**

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|---|---|
| **Sheet n°** | 8B |
| **Risk ID** | Karst in the reservoir (close to Rogun city)<br>Reservoir system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geological / Geotechnical / Geomechanical |
| **Level 3** | Karst in the reservoir (close to Rogun city) |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Reservoir system | Rogun city |
| | | |
| | | |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Salt/gypsum dissolution at higher rate after impounding in Rogun City area.** | Unlikely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Slide or settlement in inhabited areas of Rogun City.** | Extreme |

| | **Risk** |
|---|---|
| | 🟨 |
| **ADOPTED** | 🟨 |

**Comments**

**Comments**

## MITIGATION MEASURES

**Recommended mitigation measures**

**1. Modelling and survey.**

Natur **/ Monitoring of slopes.**

**/ Detailed design of mitigation measures.**

**Recommended mitigation measures**

**1. Monitoring alert induces ressettlement of population.**

**/ Survey of karst in the area of Rogun city.**

**Comments**

**Comments**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Salt/gypsum dissolution at higher rate after impounding in Rogun City area.** | Unlikely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Slide or settlement in inhabited areas of Rogun City.** | Major |

| | **Risk** |
|---|---|
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**Comments**

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|---|---|
| **Sheet n°** | 9 |
| **Risk ID** | Salt intrusion in RB<br>Dam system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟩 | 🟩 |

IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Salt intrusion in RB |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Main dam |
| | | |
| | | |
| | | |
| | | |

DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Dissolution of considerable salt mass.** | Rare |

| **Comments** |
|---|
| |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Foundation settlement and leakage.** | Extreme |

| **Comments** |
|---|
| **a. "Catastrophic" only if settlement leads to dam failure.** |

| | |
|---|---|
| | **Risk** |
| | 🟩 |
| **ADOPTED** | 🟩 |

MITIGATION MEASURES

| **Recommended mitigation measures** |
|---|
| **1. Deep drilling to confirm the absence of large salt dome.** |

Natur

| **Comments** |
|---|
| |

| **Recommended mitigation measures** |
|---|
| **1. Extend the grout curtain as needed.** |

| **Comments** |
|---|
| |

RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Dissolution of considerable salt mass.** | Rare |

| **Comments** |
|---|
| |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Foundation settlement and leakage.** | Insignificant |

| **Comments** |
|---|
| |

| | |
|---|---|
| | **Risk** |
| | 🟩 |
| **ADOPTED** | 🟩 |

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|---|---|
| **Sheet n°** | 10A |
| **Risk ID** | RB-DS important instability<br>Dam system / Flood management system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | RB-DS important instability |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Main dam |
| | Dam system | Stage 1 dam |
| 2 | Flood management system | Surface spillway |
| | Flood management system | Tunnels |
| | | |

DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Landslide during construction.** | Rare |
| **2 Triggered landslide after impounding.** | Likely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. River damming, eventual collapse of natural dam.** | Moderate |
| **2. Damming river downstream, dammage to tunnels/surface spillway.** | Moderate |

| | **Risk** |
|---|---|
| | 🟩 |
| | 🟨 |
| **ADOPTED** | 🟨 |

**Comments**

**Comments**

MITIGATION MEASURES

**Recommended mitigation measures**

**1 - 2 Treat unstable massess (reshape slope, drainage)**
**/ Assess piezometry/permeability and design appropriate drainage of the slope**
**/ Design adequate grout curtain in the Right Bank**
**/ Monitoring slope and piezometry.**

**Recommended mitigation measures**

**1 - 2. Extend the grout curtain as needed.**

Natural

**Comments**

**Comments**

RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Landslide during construction.** | Moderate |
| **2 Triggered landslide after impounding.** | Rare |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. River damming, eventual collapse of natural dam.** | Minor |
| **2. Damming river downstream, dammage to tunnels/surface spillway.** | Minor |

| | **Risk** |
|---|---|
| | 🟩 |
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**Comments**

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|---|---|
| **Sheet n°** | 10B |
| **Risk ID** | RB-DS important instability<br>Dam system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | RB-DS important instability |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Main dam |
| | Dam system | Stage 1 dam |
| | | |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Trigger landslide > 10 $\mathrm{Mm}^3$ after impounding.** | Unlikely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Weakness and eventually failure of the dam right Abutment.** | Extreme |

| | **Risk** |
|---|---|
| | 🟨 |
| **ADOPTED** | 🟨 |

**Comments**

**Comments**

## MITIGATION MEASURES

**Recommended mitigation measures**

**1. Assess piezometry/permeability and design appropriate drainage of the slope**
**/Design adequate grout curtain in the Right Bank**
**/Monitoring slope and piezometry.**

**Comments**

**Recommended mitigation measures**

**Comments**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Trigger landslide > 10 $\mathrm{Mm}^3$ after impounding.** | Rare |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Weakness and eventually failure of the dam Right Abutment.** | Extreme |

| | **Risk** |
|---|---|
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**Comments**

## GENERAL INFORMATION

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|---|---|
| **Sheet n°** | 11 |
| **Risk ID** | Long-term creeping of faults<br>Dam system / Flood management system / Power & Energy system |

| Risk evaluation | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟧 | 🟨 |

## IDENTIFICATION

| CAUSE | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Long-term creeping of faults |

| IMPACT | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Cofferdam |
| | Dam system | Main dam |
| 2 | Flood management system | Diversion Tunnels 1,2,3 |
| | Flood management system | Mid Level tunnels 1,(2) |
| 3 | Power & Energy system | Powerhouse |
| | Power & Energy system | Penstock |

## DESCRIPTION (before mitigation)

| CAUSE (S) | Likelihood |
|---|---|
| **1. Creeping movement Ionakhsh / Fault 35.** | Almost certain |
| **2. Tilting of block between Ionakhsh Fault and Fault 35.** | Almost certain |
| **3. Creeping of Fault 70 or subsidiary faults.** | Likely |

| IMPACT (S) | Evaluation | Risk |
|---|---|---|
| **1. Deformation of dam foundation (around 0.3m in 100 years).** | Minor | 🟩 |
| **2. Damage to hydraulic tunnel lining, may lead to collapse.** | Major | 🟧 |
| **3. Progressive inclination of turbines axis.** | Major | 🟧 |
| | **ADOPTED** | 🟧 |

### Comments

**a. Long term creeping movement of faults and consequent block rise due to tectonic stresses.**
**Ionakhsh Fault: creeping assumed not to be more than 3mm/year: 2mm/year for wings of Ionakhsh Fault, 1mm additional for tectonic lens, hence 3mm/year of cumulative movement distributed along the fault (1970-1980's measurements).**
**Fault 35: according to period measurements, 2.3mm/year of vertical movement**
**b. Slow tilting of the block between Ionakhsh and Fault 35 is evidenced by 1970-1980's measurements, which is likely to result in progressive inclination of turbines axis.**
**c. Accomodation of creeping movements probably trigger some slow accomodation movements between the two faults (Fault 70 or others): rate of movement unknown.**

### Comments

**a. Impact over the dam body of fault creeping assessed as minor, since filters and organs for watertightness of the dam are designed to cope with the movements, which should not exceed some 0.3m in 100 years.**
**b. Consequences of creeping on hydraulic tunnels may be dramatic since rapid scouring of ground through cracked lining by water under high velocity may rapidly lead to tunnel collapse; cavitation and headlosses are other consequences, which impact is hower assessed lower than scouring**
**c. Progressive inclination of the turbines axis is of major consequences, since it would reduce the performances of the turbines, and could affect production of the scheme.**

## MITIGATION MEASURES

Natural

### Recommended mitigation measures

### Recommended mitigation measures

**1. Resuming precise monitoring to confirm values; adequate dam design. Adaptation of dam design (filters and location of watertightness organs**

**2. Special design of tunnel lining where crossing creeping faults**

**3. Resuming precise monitoring; provision for rectification of turbnies axis.**

### Comments

**a. Precise measurement should resume to confirm figures for fault creeping and allow further design adaptation if required**
**b. With regard to tilting of the block between Ionakhsh Fault and Fault 35, measurements should also resume to monitor precisely this movement. All measures shall be taken, according to the awaited incliniation of turbine axis to rectify their position in due time, so that production remains at normal levels.**
**c. Precision measurements along main subsidairy faults within the block should be performed as well along the main discontinuities susceptible to accomodate to tilting and creeping movements, and determine if their rate may be prejudiciable to the scheme.**

### Comments

**a. The core location is designed such as to avoid creeping faults, and dam filters such as support the deformation.**
**b. Contemplate re-ajusting turbines axis at regular intervals to be determined on the basis of tilitng measuremetns in the power house**
**c. Special design to avoid damage to the hdyraulic tunnels (covered by the mitigation works against co-seismic displacement of faults)**
**d. Close monitoring of potentially creeping faults, including Fault 70 and subsidiaries)**

## RESIDUAL RISK (after mitigation)

| CAUSE (S) | Likelihood |
|---|---|
| **1. Creeping movement Ionakhsh / Fault 35.** | Almost certain |
| **2. Tilting of block between Ionakhsh Fault and Fault 35.** | Almost certain |
| **3. Creeping of Fault 70 or subsidiary faults.** | Likely |

| IMPACT (S) | Evaluation | Risk |
|---|---|---|
| **1. Deformation of dam foundation (around 0.3m in 100 years).** | Minor | 🟩 |
| **2. Damage to hydraulic tunnel lining, may lead to collapse.** | Moderate | 🟨 |
| **3. Progressive inclination of turbines axis.** | Moderate | 🟨 |
| | **ADOPTED** | 🟨 |

### Comments

**a. Monitoring not implemented in all locations, or with insufficient accuracy.**
**b. Interpretation of results from monitoring not implemented in time, or inadequate, leading to wrong assessment of the real displacements/tilting.**

### Comments

**a. With regard to long-term creeping of faults, as hydraulic tunnels crossing Ionakhsh Fault and Fault 35 will be in operation 15 years maximum, the risk of unnotice of substantial movements is assumed moderate; Fault 70 can be observed in the power house.**
**b. If action is not taken facing substantial tilting of turbine axis, the risk is be important, since it will impact the performances of the turbines and the power generation.**
**c. Weakness in maintenance and operation, especially with regard to turbines, or failing to repair a sbustantial creeping movement remains major.**

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|---|---|---|

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|---|---|
| **Sheet n°** | 12 |
| **Risk ID** | Mudflows from Obishur R. and other streams<br>Access / Dam system / Flood management system / Power & Energy system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟧 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Mudflows from Obishur R. and other streams |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Access | Permanent access |
| 2. | Dam system | Stage 1 dam |
| | Dam system | Cofferdam |
| 3 | Flood management system | Diversion Tunnels 1,2,3 |
| 4 | Power & Energy system | Tailrace |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** | **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|---|---|
| **1. Large mudflows running down the Obi-Shur River.** | Moderate | **1. Sudden raising of tailwater level; access flooding.** | Minor | 🟩 |
| **2. Large mudflows running down the Obi-Shur River.** | Moderate | **2. Sudden raising of tailwater level; flooding of construction site.** | Moderate | 🟩 |
| **3. Large mudflows running down the Obi-Shur River.** | Moderate | **3. Sudden raising of tailwater level; blockage of diversion tunnels.** | Extreme | 🟧 |
| **4. Large mudflows running down the Obi-Shur River.** | Moderate | **4. Sudden raising of tailwater level; tailrace tunnels.** | Extreme | 🟧 |
| | | | **ADOPTED** | 🟧 |

**Comments**

**a.Almost every year, and sometimes several times a year, mudflows occur in the Obi-Shur Valley; one of these mudflows was partly the cause of the washing-out of the already constructed part of the dam in 1993.**
**Such mudflows may temporarily dam the Vakhsh River and cause rapid raise of the tailwater level.**

**Comments**

**a. Major risk if access are flooded.**
**b. If the construction site is flooded, the cofferdam or the already constructed part of the dam may be washed out.**
**c. If the diversion tunnels are blocked by an excessive tailwater level, there may be impossibility to control the water level, and subsequent overtopping of the dam under construction.**
**d. A sudden tailwater raising may flood the power house and generating components of the scheme.**

## MITIGATION MEASURES

Natur

**Recommended mitigation measures**

**1 - 2 - 3 - 4. Completion of actual dam, study of flow dynamics**

**/ Adequate monitoring for early detection of mudflows**

**/ Operating and maintenance instructions**

**/ Provision for rapid clearing of debris from the Vakhsh River.**

**Recommended mitigation measures**

**1 - 2 -3 -4 Monitoring should allow alert to be transmitted to the powerstation.**

**/ Extensive survey of the mudflow phenomenon is necessary before stage 1 construction (gate closure for powerhouse protection).**

**/ Retain the larger debris behind the dam, allow passage of fine fraction.**

**Comments**

**a. Completion of the dam actually under construction to contain the devris, but further dams or other means of retaining debris are to be studied and constructed.**
**b. An adequate monitoring should be installed along the Obi-Shur Valley to detect mudflow occurrence as soon as possible.**
**c. Operation instructions to be adapted such as to allow stoppage of production and all access closure before arrival of the mudflow in the Vakhsh River.**

**Comments**

**a. A study of the dynamics of mudflows in the Obi-Shur Valley and scenario of repetition of the mudflows is necessary for design of adeqaute mitigation measures.**
**b. The monitoring of the valley should allow rapid transmission of alert signals to the power station ,so that all measures can be taken in urgence before the raise of the tailwater levels.**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** | **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|---|---|
| **1. Large mudflows running down the Obi-Shur River.** | Moderate | **1. Sudden raising of tailwater level; access flooding.** | Minor | 🟩 |
| **2. Large mudflows running down the Obi-Shur River.** | Moderate | **2. Sudden raising of tailwater level; flooding of construction site.** | Minor | 🟩 |
| **3. Large mudflows running down the Obi-Shur River.** | Moderate | **3. Sudden raising of tailwater level; blockage of diversion tunnels.** | Minor | 🟩 |
| **4. Large mudflows running down the Obi-Shur River.** | Moderate | **4. Sudden raising of tailwater level; tailrace tunnels.** | Minor | 🟩 |
| | | | **ADOPTED** | 🟩 |

**Comments**

**a. The volume of the mudflows are so large and they are so frequent, that rapidly, retaining capacity will be nil.**
**b. Adequate monitoring is to found and installed.**

**Comments**

**a. Insufficient retaining capacity of dams in Obi-shur Valley will not imede sudden rising of tailwater levels and consequences**

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|---|---|
| **Sheet n°** | 13 |
| **Risk ID** | Leakage from reservoir<br>Reservoir system / Power & Energy system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Leakage from reservoir |

| | **IMPACT** | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Reservoir system | Karstic structures |
| 2 | Reservoir system | Gulzidan fault area |
| 3 | Power & Energy system | Powerhouse |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Karstic structures under reservoir level.** | Likely |
| **2. Leaching of salt within Gulizindan Fault.** | Likely |
| **3. Insufficient input parameters of hydrogeological model.** | Likely |

| **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|
| **1. Leakage from reservoir through karstic structures.** | Moderate | 🟨 |
| **2. Leakage through dissolution zone above salt in Gulizindan Fault.** | Moderate | 🟨 |
| **3. Excess inflow of water in power house and other underground works.** | Moderate | 🟨 |
| | **ADOPTED** | 🟨 |

**Comments**

**a. Presence of karstic features like dissolution zones within gypsum or limestone, in the right bank, with inlet and outlet below reservoir level**
**b. Leaching of salt along the Gulizindan Fault, between reservoir and downstream of the dam site (Obi-Shur Valley).**
**c. The hydrogeological model presently does not incorporate all the right bank, and calibration shall be made taking this inot account. Underestimation of hydraulic conductivities in the hydrogeological model is dealt possible (especially for geotechnical zone IV).**

**Comments**

**a. Unacceptable leakage through the right bank disturbed zone, which may lead to landslides in the river.**
**b. Loss of water from the reservoir through the dissolved zone above salt head in Gulizindan Fault.**

## MITIGATION MEASURES

**Recommended mitigation measures**

Natur
**1. Detailed investigations of right bank below reservoir level.**
**2. Grouting of Gulizindan Fault extremities; monitoring.**
**3. Improvement of hydrogeological model and input data.**

**Recommended mitigation measures**

**1. Should allow precise assessment of the risk of leakage.**
**2. Should avoid the risk of leakage through the fault.**
**3. Better calibration of model and imporvement of results.**

**Comments**

**a. Detailed geological investigations of the right bank below reservoir level (investigation galleries) should allow understanding the exact nature and arrangement of geological formations; remedail measures can be designed in time.**
**b.Geological investigations of Gulizindan Fault features are to be carried out, and grouting of the lower end to allow leakage; monitoring of water discharges shall be carried out there.**
**c. The hydrogeological model shall be extended to include the right bank, once its structure below reservoir level known, calibrated with all available data, taking into account infliltrations on the plateau, balance of inflows and outflows checked with respect ot various possible values of hydraulic conductivity.**

**Comments**

**a. Once the geological structure of the right bank below reservoir elevation understood, risk of leakage can be assessed or discarded, and eventual remedial measures designed and implemented before impounding.**
**b. Grouting of its lower end should avoid leakage through Gulizindan Fault, but investigation of upper end also recommended, since measures may be taken there as well; monitoring should allow to check if leakage occurs.**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Karstic structures under reservoir level.** | Likely |
| **2. Leaching of salt within Gulizindan Fault.** | Likely |
| **3. Insufficient input parameters of hydrogeological model.** | Unlikely |

| **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|
| **1. Leakage from reservoir through karstic structures.** | Minor | 🟩 |
| **2. Leakage through dissolution zone above salt in Gulizindan Fault.** | Minor | 🟩 |
| **3. Excess inflow of water in power house and other underground works.** | Minor | 🟩 |
| | **ADOPTED** | 🟩 |

**Comments**

**a. If only limited investigations investigations take place before impounding, which do not recognise the internal structure of the right bank, allowing precise assessment over possible leakage.**
**b. No monitoring of water discharge around lower end of the Gulizindan Fault.**
**c. Impossibility to realistically model hydrogeological conditions of the right bank because of the lack of knowledge of geological structures and adequate input parameters.**

**Comments**

**a. It is supposed for the residual risk that dedicated investigations were carried out, such as the geological structure of the right bank is better known than today; remedial measures are to be designed after beginning impoundment of the dam.**
**b. In absence of observation and monitoring means, leakage may occur unnoticed; amount is supposed to be acceptable thanks to grouting, but the risk of leakage increase exists (salt dissolution within the Gulizindan Fault)**
**c. Uncertaintis supposed to be reduced to an acceptable level.**

GENERAL INFORMATION

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| | |
|---|---|
| **Sheet n°** | 14 |
| **Risk ID** | Dam excavations slope instabilities<br>Dam system |

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| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Dam excavations slope instabilities |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Main dam |
| | Dam system | Stage 1 dam |
| | | |
| | | |
| | | |

DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Rockfalls or landslide occurring on the dam site.** | Almost certain |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Casualties and damages to construction means / Slowdown of the construction.** | Moderate |

| | **Risk** |
|---|---|
| | 🟨 |
| **ADOPTED** | 🟨 |

**Comments**

**a. Rockfalls occur at almost every rainy episode on the dam site; landslides or rockslides of limited volume may also occur during excavation of the dam foundation, and during the dam construction period (more than 15 years).**

**Comments**

**a. Rockfalls, rockslides or landslides running down to the river during dam foundation excavations and further, dam construction, will cost casualties and damages to construction means, as well as unsafe atmosphere on the work site.**
**b. Necessity to cope with regular rockfalls, by stopping the works, may slowdown the construction pace and impact schedule.**

MITIGATION MEASURES

Natural

**Recommended mitigation measures**

**1. Scaling and reinforcement of all slopes over the dam site**
**/ Identification and monitoring of the most threatening rock masses**
**/ Interruption of the works at every rainy episode or during heavy snow melting.**

**Recommended mitigation measures**

**1. Securing properly all slopes over the dam should avoid dramatic events.**
**/ Monitoring to allow alert in case of increased rate of movement**
**/ Protection of personal and construction means**

**/ State of the art technics and standards. Coordination. Security.**

**Comments**

**a. Detailed inspection of all slopes over the dam site should be performed, determining the way of securing the site; scaling (i.e. removing of loose rocks) is to be carried out, followed by adequate support by anchors and reinforced wiremesh, together with installation of rockfall protection devices.**
**b. In this case, the mitigation measure is limited to the monitoring of the most threatening rock masses.**
**c. Interruption of works on the dam site at every rainy episode or dangerous circumstances (e.g. heavy snow melting).**

**Comments**

**a. Together with monitoring and regular inspection, should avoid occurrence of major rockfalls or landslides.**
**b. Should allow to alert in case of dangerous situation due to increased rates or accelerations of movements of unstable masses.**
**c. Procedures of immediate interruption of work to be worked out for protection of personal and machines during dam foundation excavation and dam construction.**

RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Rockfalls or landslide occurring on the dam site.** | Likely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Casualties and damages to construction means.** | Minor |

| | **Risk** |
|---|---|
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**a. Securing all slopes as recommended requires immediate starting of the process, and given the surface of slopes over the dam site, securing entirely the dam site can take a very long time and my be incomplete.**
**b. Inadequate or incomplete monitoring of most threatening unstable masses.**
**c. Rockfalls or rockslides triggered by an earthquake will occur without warning.**
**d. Given the many years the dam construction is to last, a progressive loss of efficiency of the securing measures can take place.**

**Comments**

**a. Even if incomplete, it is supposed here that a great majority of the slopes have been secured, potential instabilities or rockfalls remaining very small in volume.**
**b. Movement of unstable masses will remain unnoticed until their fall**
**c. Impact of an earthquake event on the work site can be major, with many rockfalls triggered without any warning.**
**d. Loss of efficiency of protective measures will progressively lead back to the original conditions.**

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|---|---|
| **Sheet n°** | 15A |
| **Risk ID** | Co-sismic displacements<br>Dam system |

| Risk evaluation | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟩 | 🟩 |

IDENTIFICATION

| CAUSE | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Co-sismic displacements |

| IMPACT | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Main dam |
| | Dam system | Stage 1 dam |
| | | |
| | | |
| | | |

DESCRIPTION (before mitigation)

| CAUSE (S) | Likelihood |
|---|---|
| **1. Co-sismic displacement along Ionakhsh Fault (assumed 1m) / along Fault 35 or subsidiaries (assumed 0.1m).** | Rare |

| IMPACT (S) | Evaluation |
|---|---|
| **1. Damage to dam foundation deformation.** | Minor |

| | Risk |
|---|---|
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**a. Co-sismic displacement along Ionakhsh Fault during an earthquake : 1m maximum according to seismo-tectonic studies.**
**b. Co-sismic displacement along Fault 35 and subsidiary faults of the same family during an earthquake: 0.1m maximum according to seismo-tectonic studies.**

**Comments**

**a. Co-sismic displacement on Ionakhsh Fault will affect the stage 1 dam body.**

MITIGATION MEASURES

Natur

**Recommended mitigation measures**

**Comments**

**Recommended mitigation measures**

**1. Dam filters and watertight organs designed to accept the deformations.**

**Comments**

**a. Dam designed to tolerate the corresponding deformations of the foundation.**

RESIDUAL RISK (after mitigation)

| CAUSE (S) | Likelihood |
|---|---|
| **1. Co-sismic displacement along Ionakhsh Fault (assumed 1m) / along Fault 35 or subsidiaries (assumed 0.1m).** | Rare |

| IMPACT (S) | Evaluation |
|---|---|
| **1. Damage to dam foundation deformation.** | Insignificant |

| | Risk |
|---|---|
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**Comments**

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|---|---|
| **Sheet n°** | 15B |
| **Risk ID** | Co-sismic displacements<br>Flood management system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟧 | 🟨 |

IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Co-sismic displacements |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Flood management system | Diversion Tunnels 1,2,3 |
| | Flood management system | Mid Level tunnels 1,(2) |
| 2 | Flood management system | High level Tunnels 1, (2), (3) |
| 3 | Flood management system | Surface spillway |
| | | |

DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Co-sismic displacement along Ionakhsh Fault (assumed 1m).** | Moderate |
| **2. Co-sismic displacement along Fault 35 or subsidiaries (assumed 0.1m).** | Moderate |
| **3. Co-sismic displacement along Fault 35 or subsidiaries (assumed 0.1m).** | Moderate |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Damage to diversion tunnels and mid-level outlet 1.** | Extreme |
| **2. Damages to high level tunnels depending on moving fault location.** | Moderate |
| **3. Damages to surface spillway depending on moving fault location.** | Moderate |

| | **Risk** |
|---|---|
| | 🟧 |
| | 🟩 |
| | 🟩 |
| **ADOPTED** | 🟧 |

**Comments**

**a. Co-sismic displacement along Ionakhsh Fault during an earthquake : 1m maximum according to seismo-tectonic studies.**

**b. The risk only counts during the useful life of tunnels DT3 and ML1, only during construction period for less than about 10 years.**

**c. Co-sismic displacement along Fault 35 and subsidiary faults of the same family during an earthquake: 0.1m maximum according to sismo-tectonic studies.**

**d. Regarding diversion tunnels and mid-level outlet 1, co-sismic displacement along Fault 35 can induce some damages, but moderate comparing to these induced by Ionakhsh Fault.**

**Comments**

**a. Only the DT3 and middle oultet 1 are crossed by Ionakhsh Fault. Co-sismic displacement on Ionakhsh Fault will affect the portals of the diversion tunnels 1 and 2, as well as diversion tunnel 3 and the mid-level outlet 1; mis-alignment of tunnel blocks and damage to lining of the hydraulic tunnels may lead rapidly to tunnel collapse due to ground scouring by water under high velocity; cavitation and headlosses also expected.**

**b. In the case of Surface Spillway, being and outdoor structures, monitoring and repair works become easier. The project is less sensitive to this kind of risk.**

**c. Co-sismic displacement along Fault 35 or other faults of the same family is to affect a great number of tunnels, almost all of the principal hydraulic and access tunnels; damage to lining of hydraulic tunnels may rapidly lead to tunnel collapse due to ground scouring by water under high velocity; cavitation and headlosses also expected.**

MITIGATION MEASURES

**Recommended mitigation measures**

Natural

**Comments**

**Recommended mitigation measures**

**1 - 2 - 3. Special design of lining of hydraulic tunnels crossing potentially active faults, avoiding scouring.**

**/ Allow stopping the operation and immediate inspection and repair of all hydraulic tunnels after a major earthquake where co-sismic displacement may or has occurred. For DT3, a second gates cavern in order to allow sectionnal inspection and repair works. For Middle Outlet 1, an enlarge colvert in the crossing area.**

**Comments**

**a. Special design to reduce the impact of a co-sismic movement on the tunnel and above all, avoid scouring (overexcavation and placement of rings of reinforced concrete lining separated by joints)**
**b. Fitting the hydraulic tunnels with adequate stoplogs/valves to allow rapid inspection of hydraulic tunnels; available means for repair.**
**c. A monitoring system to detect tunnel shearing, and seepage.**

RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Co-sismic displacement along Ionakhsh Fault (assumed 1m).** | Moderate |
| **2. Co-sismic displacement along Fault 35 or subsidiaries (assumed 0.1m).** | Moderate |
| **3. Co-sismic displacement along Fault 35 or subsidiaries (assumed 0.1m).** | Moderate |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Damage to diversion tunnels and mid-level outlet.** | Major |
| **2. Damages to high level tunnels depending on moving fault location.** | Minor |
| **3. Damages to surface spillway depending on moving fault location.** | Minor |

| | **Risk** |
|---|---|
| | 🟨 |
| | 🟩 |
| | 🟩 |
| **ADOPTED** | 🟨 |

**Comments**

**a. If co-sismic movement occurs along a fault not fitted with specially designed lining.**
**b. If the special design measures reveal not adequate, or not completely effective, especially towards scouring, e.g. in case the fault shear movement concentrates along a very narrow strip, like a saw cut.**

**Comments**

**a. If movement occurs where no special measures have been, taken the level of risk is same as without mitigation measure.**
**b. If special design measures where crossing potentially active faults is not effective, the good implementation of reinforced concrete lining should limit penetration in the ground of the high-velocity flowing water, and reinforcement preserves stability for at least some time until inspection and repair can be achieved.**

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|---|---|
| **Sheet n°** | 15C |
| **Risk ID** | Co-sismic displacements<br>Power & Energy system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Co-sismic displacements |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Power & Energy system | Structures |
| 2. | Power & Energy system | Energy production |
| | | |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Co-sismic displacement along Fault 35 or subsidiaries (assumed 0.1m).** | Moderate |
| **2. Co-sismic displacement along Fault 35 or subsidiaries (assumed 0.1m).** | Moderate |

| **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|
| **1. Damages to power structures.** | Moderate | 🟩 |
| **2. Loss of production.** | Major | 🟨 |
| | **ADOPTED** | 🟨 |

**Comments**

**a. Co-sismic displacement along Ionakhsh Fault during an earthquake : 1m maximum according to seismo-tectonic studies.**

**b. Co-sismic displacement along Fault 35 and subsidiary faults of the same family during an earthquake: 0.1m maximum according to seismo-tectonic studies.**

**Comments**

**a. Displacements in powerhouse, tilting of turbine axis.**

**b. Damages to headrace and tailarce tunnels due to co-sismic displacements.**

## MITIGATION MEASURES

**Recommended mitigation measures**

**Comments**

Natural

**Recommended mitigation measures**

**1. Monitoring of powerhouse and tunnels; reinforcement measures near to fault 70.**

**2. Design allowing for a meachanical adjustment in equipment after displacements.**

**Comments**

**a. Provision taken to rapid repair of eventual dislacement along Fault 70 in the powerhouse, or readjust turbine axis.**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Co-sismic displacement along Fault 35 or subsidiaries (assumed 0.1m).** | Moderate |
| **2. Co-sismic displacement along Fault 35 or subsidiaries (assumed 0.1m).** | Moderate |

| **IMPACT (S)** | **Evaluation** | **Risk** |
|---|---|---|
| **1. Damages to power structures.** | Minor | 🟩 |
| **2. Loss of production.** | Moderate | 🟩 |
| | **ADOPTED** | 🟩 |

**Comments**

**a. If adequate re-adjustment of turbines axis is not performed because of lack of monitoring or time.**

**Comments**

**a. Re-adjustment of turbines axis not made in time will affect the performances of the turbines and energy production.**

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|---|---|
| **Sheet n°** | 16 |
| **Risk ID** | Dam materials: Inappropriate survey, inadequate materials<br>Dam system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟧 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Dam materials: Inappropriate survey, inadequate materials |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Dam during construction |
| 2 | Dam system | Dam Core |
| 3, 4 | Dam system | Dam |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| CAUSE (S) | Likelihood |
|---|---|
| 1. Wrong assessment of quantities/quality of available materials. | Rare |
| 2. Excessive natural water content of deposit 17. | Likely |
| 3. Ineffective processes for fine fraction increase. | Likely |
| 4. Segregation of materials at placement | Moderate |

| IMPACT (S) | Evaluation | Risk |
|---|---|---|
| 1. Search for new materials sources in sufficient quantity and best quality. | Moderate | 🟩 |
| 2. Insiffucient mechanical characteristics for core of the dam. Excessive settlement of dam core. | Moderate | 🟨 |
| 3.Watertightness not ensured. | Major | 🟧 |
| 4. Insufficient mechanical characteristics, and heterogeneous distribution of materials grading. | Moderate | 🟩 |
| | **ADOPTED** | 🟧 |

**Comments**

**a. Assessment made of available quantities (in-situ and after transport and placement into the dam body) may be imprecise, especially with regard to deposit 17 for core; quality may also reveal variable.**

**b. In situ measures revealed an excessive moisture. Adapted treatments of drying are awaited.**

**c. According to available results, the proportions of fine particles (<80µm) in deposit 17 may not be sufficient for direct placement as core of the dam. Trial tests should be carried out to ensure watertightness of the core. If these tests were negative, then processes for fine content increase should be put in place.**

**d. Segregation is likely to appear for large graded materials, and for poor placement procedures.**

**Comments**

**a. Such a situation is likely to increase strongly (10%) the materials costs.**

**b. Possibilities of major issues on dam behaviour**

**c. Segregation at placement may lead to major issues of dam mechanical behaviour and watertightness.**

## MITIGATION MEASURES

**Recommended mitigation measures**

**1. Additional investigations to precise quantities and quality of materials**

**2. Checking the in situ water content and reduce moisture if implement the adequate drying process after testing efficiency**

Natur

**3. Trial test for mixing procedure. Regular monitoring during construction is also needed.**

**4. Placement procedures likely to avoid segregation are to be implemented.**

**Recommended mitigation measures**

**1. Anticipate the search for new sources of materials. More detailed previsions of material treatment and scheduling of construction**

**2. Cost estimate should considers cost for moisture control (adapted processes)**

**/ Should allow time to know how far drying is required**

**3. Should allow time to define treatment and adjust schedule. Cost already includes provisions for mixing of fines for all core volumes (conservative).**

**Comments**

**a. A monitoring program of materials characteristics should be implemented during construction in order to ensure a good material quality. Moisture, segregation, grading curves, fine content (for the core), compacted densities are to be tested all along the dam construction.**

**Comments**

**a. Will allow better adjustment of costs and schedule for dam construction materials.**
**b. May avoid resorting to other deposits for filter material.**
**c. Identification of related cost and schedule of material availability taking into account time for processing and final availability for placement into the dam body.**

## RESIDUAL RISK (after mitigation)

| CAUSE (S) | Likelihood |
|---|---|
| 1. Wrong assessment of quantities/quality of available materials. | Rare |
| 2. Excessive natural water content of deposit 17. | Unlikely |
| 3. Ineffective processes for fine fraction increase. | Moderate |
| 4. Segregation of materials at placement. | Unlikely |

| IMPACT (S) | Evaluation | Risk |
|---|---|---|
| 1. Search for new materials sources in sufficient quantity and best quality. | Minor | 🟩 |
| 2. Insufficient mechanical characteristics for core of the dam. Excessive settlement of dam core. | Moderate | 🟩 |
| 3.Watertightness not ensured. | Moderate | 🟩 |
| 4. Insufficient mechanical characteristics, and heterogeneous distribution of materials grading. | Moderate | 🟩 |
| | **ADOPTED** | 🟩 |

**Comments**

**a. Materials of required quality may not be in sufficient quantities, or material of rather low performances used for placement in some part of the dam body.**
**b. The process of drying for moisture reduction implies strict rules, which may be not completely respected.**
**d. Process for mixing particles <80µm to material from deposit 17 is not simple, and also costly; the mixing may be imperfect. Trial tests are required.**

**Comments**

**a. Locally low friction angle due to inadequate materials in the shoulder, alkali-reaction within concrete or filters not completely according to specifications.**
**b. Excessive moisture content may lead to excessive pore pressures and reduction in compacity of clay core; risk of excessive settlement of the clay core.**
**d. Irregular distribution of fine particles may leave paths for leakages within the clay core of the dam.**

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## GENERAL INFORMATION

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COYNE ET BELLIER Ingénieurs Conseils
ELECTROCONSULT
IPA Energy + Water Economics

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|---|---|
| **Sheet n°** | 17 |
| **Risk ID** | Structures-Caverns: rock excavation<br>Power & Energy system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟥 | 🟨 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Natural |
| **Level 2** | Geology / Geotechnics / Geomechanics |
| **Level 3** | Structures-Caverns: rock excavation |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Power & Energy system | Powerhouse |
| 2. | Power & Energy system | Transformers |
| | | |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Non-manageable distressing of rock between caverns.** | Almost certain |
| **2. Non-manageable distressing of rock between caverns.** | Almost certain |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Convergence of the Powerhouse cavern.** | Extreme |
| **2. Convergence of the Transformers cavern.** | Moderate |

| | **Risk** |
|---|---|
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| **ADOPTED** | 🟥 |

### Comments

**a. History of excavation of powerhouse and subsequent investigations show that support did not prevent progressive distressing of the rock mass, especially within the siltstone part of the power house cavern; exceptionally large convergence has been observed, and re-initiated by resuming of the works in the cavern in 2008.**
**b. In such conditions, close monitoring and close follow-up of monitoring data is a must; if measurements are made too late after excavation, the movements are underestimated.**
**c. If convergence movements are not closely examined or wrongly interpreted, precursors to rock failure or collapse in part of the cavern will not be possible.**

### Comments

**a. The pattern of convergences up to now does not exhibit real stabilisation, and collapse or partial failure of power house is a risk (especially siltstone part).**
**b. If inadequate monitoring is performed, or if it is not interpreted in real-time, the exact convergence movemetns and their rate, acceleration will not be known and impede prevent an eventual failure.**
**c. Wrong interpretation and lack of permanent surveying may lead to unpredictable failure or collapse, with casualties and damages.**
**d. In case of rock failure or collapse of the cavern, great damage is to occur in the rock piilars separating the power hosue cavern from the transformer cavern to the south, and from the assembly chamber to the north.**

**e. The evaluation of consequences take into account the remain works and loss of energy production.**

## MITIGATION MEASURES

Natural

### Recommended mitigation measures

**1-2. Immediate placement of heavy additional support to try to stabilise the cavern.**

**/ Performance of real time monitoring, with additional means.**

**/ Extension of cavern towards east, leaving the siltstone part concreted.**

### Recommended mitigation measures

**1. Monitoring of the powerhouse cavern. Should allow close observations and allow alert to be given in time in case of failure.**

**2. Monitoring of the transformers caverns. Should allow close observations and allow alert to be given in time in case of failure.**

**1-2. Would allow construction for units 5 and 6 in more favourable geological conditions.**

### Comments

**a. Placement of especially heavy reinforcement is required for stabilising the movements in the already excavated siltstone part of the power house cavern; if adequately done, and adequate support placed during the further construction steps, risk of collapse or rock failure in the cavern will be reduced.**
**b. In any case, a close monitoring, in real-time is to be implemented, as well as permanent observation (e.g. main crack opening follow-up, noise, etc.); interpretation should follow immediately.**
**c. Leaving uncompleted and concreting the siltstone part of the cavern is a possibility, which will solve the issue of the siltstone part of the cavern.**

### Comments

**a. Placement of heavy additional support in the existing parts of the power hosue cavern and in the parts remaining to be excavated may possibly allow stabilisation of the movements and prevent rock failure or collapse of the cavern**
**b. Close, real-time monitoring of movements and immediate interpretation would allow alert to be given in case of major risk of rock failure or collapse**
**c. Provided that extension of the cavern towards the east is done with adequate support, avoiding distressing of rock masses (Karakuz Formation more favourable, with a majority of sandstone), this extension is likely possible under much easier conditions than the present one prevailing in siltstones; units 5 and 6 are to be moved there, while the siltstone part of the cavern is concreted to definitely stabilise it (or serve as erection bay)**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Non-manageable distressing of rock between caverns.** | Likely |
| **2. Non-manageable distressing of rock between caverns.** | Likely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Convergence of the Powerhouse cavern.** | Moderate |
| **2. Convergence of the Transformers cavern.** | Minor |

| | **Risk** |
|---|---|
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| **ADOPTED** | 🟨 |

### Comments

**a. There is a non-negligible possibility that actually performed works do not succeed in stabilising the siltstone part of the cavern.**
**b. The risk of unpredicted rock failure or even collpase of the cavern exists if convergences do not stabilise, even with monitoring, since earthquake shaking may trigger the collpase in an unpredictable way.**
**c. There is a possiblity, considered low, to encounter locally adverse geological conditions towards east, especially when nearing to Fault 35.**

**d. A specific note has been made, evidencing the feasability study of remedial measures (RP50).**

### Comments

**a. If convergences do not stabilise, the risk of rock failure or collpase remains.**
**b. In case of failure or rock collapse, damages and extensive distressing of the rock may force to shift the cavern towards the east, such as proposed in an other mitigation measures.**
**c. If geological conditions to the east of the present cavern cannot be mastered during construction, the same risk of failure or collapse of the cavern exists.**

**Rogun HPP** **TEAS Consortium - Phase II - Risk assessment** **07/08/2014**

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|---|---|
| **Sheet n°** | 18 |
| **Risk ID** | Diversion/Tailerace tunnels: construction quality<br>Flood management system / Power & Energy system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟥 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Technical |
| **Level 2** | Maintenance & Operation |
| **Level 3** | Diversion/Tailerace tunnels: construction quality |

**IMPACT**

| | SYSTEM (S) | COMPONENT (S) |
|---|---|---|
| 1 | Flood management system | Diversion Tunnels 1,2,3 |
| 2 | Power & Energy system | Tailrace |
| | | |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| CAUSE (S) | Likelihood |
|---|---|
| 1. Global structure Instability in DTs. | Likely |
| 2. Global structure Instability in DTs. | Likely |

| IMPACT (S) | Evaluation |
|---|---|
| 1. Availability and decreased discharge capacity of diversion tunnels. | Extreme |
| 2. Availability of tailrace tunnels. | Major |

| | Risk |
|---|---|
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| **ADOPTED** | 🟥 |

**Comments**

a. The structures, during construction, were modified compared with the original design. The present configuration does not guarantee residual bearing capability against future variation of load conditions. The Design External water load pressure value is the result of the Seepage calculation Model with an accuracy of ± 100 kPa. The present structures configuration does not guarantee safety margin against load variation in the range of model accuracy. Because of modifications made during construction there is no absolute certainty of compliance between structures as built and design configuration.

Natural

**Comments**

a. (1) This impact is related to collapse of Diversion Tunnels stretches during dam construction period.
b. (2) This impact is related to collapse of Diversion tunnels stretches used as tailrace tunnels during power plant operation period.

c. If DTs tunnels are not available, a stage 1 dam overtopping may occur.

## MITIGATION MEASURES

**Recommended mitigation measures**

1-2. Implementation of drainages system
/ Installation of Rock Dowels System.
/ Construction of a new inner reinforced concrete lining

**Comments**

a. It is assumed that the remedial mitigation measures will be designed on the base of the recommended measures proposed for the economical evaluation of the alternatives and strictly respecting the Design Criteria exposed in the Phase 2 report and specialized case by case taken into account the local conditions.

**Recommended mitigation measures**

**Comments**

## RESIDUAL RISK (after mitigation)

| CAUSE (S) | Likelihood |
|---|---|
| 1. Global structure Instability in DTs. | Moderate |
| 2. Global structure Instability in DTs. | Moderate |

| IMPACT (S) | Evaluation |
|---|---|
| 1. Availability and decreased discharge capacity of diversion tunnels. | Moderate |
| 2. Availability of tailrace tunnels. | Moderate |

| | Risk |
|---|---|
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| **ADOPTED** | 🟩 |

**Comments**

**Comments**

**Rogun HPP** **TEAS Consortium - Phase II - Risk assessment** **07/08/2014**

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|---|---|
| **Sheet n°** | 19 |
| **Risk ID** | Design studies<br>Dam system/Flood management system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
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**IDENTIFICATION**

| **CAUSE** | |
|---|---|
| **Level 1** | Technical |
| **Level 2** | Design |
| **Level 3** | Design studies |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Dam construction |
| | Flood management system | Tunnels |
| | | |
| | | |
| | | |

**DESCRIPTION (before mitigation)**

| **CAUSE (S)** | **Likelihood** |
|---|---|
| 1. Lack of data. | Moderate |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| 1. Loss of function. Increased costs and delay. | Major |

| | **Risk** |
|---|---|
| | 🟨 |
| **ADOPTED** | 🟨 |

**Comments**

a. Inappropriate interpretation,wrong choice or insufficient margin of safety are others causes which can impact the global construction, with a rare likelihood and major evaluation of damages.

**Comments**

**MITIGATION MEASURES**

**Recommended mitigation measures**

1. Adapted investigation campaigns.

/ Exchanges, Independant reviews and recommandations for detailed design and construction phase.

/ State of the art techniques and standards.

Natural

**Comments**

**Recommended mitigation measures**

**Comments**

**RESIDUAL RISK (after mitigation)**

| **CAUSE (S)** | **Likelihood** |
|---|---|
| 1. Lack of data. | Unlikely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| 1. Loss of function. Increased costs and delay. | Major |

| | **Risk** |
|---|---|
| | 🟩 |
| **ADOPTED** | 🟩 |

**Comments**

**Comments**

**Rogun HPP** **TEAS Consortium - Phase II - Risk assessment** **07/08/2014**

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|---|---|
| **Sheet n°** | 20 |
| **Risk ID** | Maximum head in tunnels<br>Dam system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟥 | 🟨 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Technical |
| **Level 2** | Design |
| **Level 3** | Maximum head in tunnels |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Main dam |
| | Dam system | Stage 1 dam |
| | | |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Failure of DT2, DT3, or remote spillways due to high operating head.** | Likely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| **1. Loss of control. Dam overflooding.** | Extreme |

| | **Risk** |
|---|---|
| | 🟥 |
| **ADOPTED** | 🟥 |

**Comments**

**a. Under current conditions (HPI design), tunnels are to be operated under high heads (as much as about 200m for DT2).**

**b.These tunnels are supposed to work permanently and over several years with maximum head in order of the magnitude of 150 / 160 m (DT3, Remote Spillways) and up to 200 m for DT2.**

Natur

**Comments**

**a. Such unprecedented high head for permanent, long terms (several years during construction) operation, may lead to loss of control of tunels because of gate vibration and cavitation. If tunnels fail there will be loss of control of floods heading to dams ( stage 1 and Main dam) collapse.**

**b. If tunnel fail, dam (stage 1 and main dam) will be overflood.**

**c. After construction, the surface spillway make possible the overflood.**

## MITIGATION MEASURES

**Recommended mitigation measures**

**1. Reducing maximum operating head to 120m.**

**Comments**

**a. See report on Flood managment during construction.**

**b. Lower operation head, will required a higher number of tunnels for flood managament during construction.**

**Recommended mitigation measures**

**Comments**

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| **1. Failure of DT2, DT3, or remote spillways due to high operating head.** | Unlikely |

| **IMPACT (S)** | **Impact** |
|---|---|
| **1. Loss of control. Dam overflooding.** | Extreme |

| | **Risk** |
|---|---|
| | 🟨 |
| **ADOPTED** | 🟨 |

**Comments**

**Comments**

**Rogun HPP** **TEAS Consortium - Phase II - Risk assessment** **07/08/2014**

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|---|---|
| **Sheet n°** | 21 |
| **Risk ID** | Construction schedule<br>Dam system/Flood management system |

| **Risk evaluation** | |
|---|---|
| **Before mitigation** | **After mitigation** |
| 🟨 | 🟩 |

## IDENTIFICATION

| **CAUSE** | |
|---|---|
| **Level 1** | Technical |
| **Level 2** | Construction |
| **Level 3** | Construction schedule |

| **IMPACT** | | |
|---|---|---|
| | **SYSTEM (S)** | **COMPONENT (S)** |
| 1. | Dam system | Dam construction |
| | Flood management system | Tunnels |
| | | |
| | | |
| | | |

## DESCRIPTION (before mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| 1. Not adapted equipment / Poor coordination between designer, owner engineer and contractor / Not adequate engineering / Stoppage of funding / Delay on fuel delivery / Increase of fuel cost. | Likely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| 1. Over delay / Over cost for dam construction. | Moderate |

| **Risk** |
|---|
| 🟨 |
| **ADOPTED** 🟨 |

**Comments**

a. Challenging project which requires high quality equipment and very qualified contractor and engineering firms.
b. Duration of overall project is very long (more than 10 years)
c. Very important cost (more than 3 billions of US$).

**Comments**

a. The implementation schedule foresees a lot of activities that are carried out in parrallel.
b. The dimensions of the dam are huge.
c. The evaluation includes the loss of energy production.

## MITIGATION MEASURES

**Recommended mitigation measures**

1. Highly qualified contractor
/ Highly qualified engineering firms
/ The construction starts only if the financement is reliable to ensure the end of construction. In effect, the Stage 1 dam is not designed for important return period flood.

Natur

**Recommended mitigation measures**

1. Advance on the planning
/ Increasing of the security factor design.

**Comments**

a. The contractor that will be selected must have a experience in a very large hydropower projects, as well as the engineering firms involve as owner engineer and designer.

**Comments**

a. It should be pointed out that increasing the security factor of design structure is very low compared to the cost of damages and the delay on the production of electricity.

## RESIDUAL RISK (after mitigation)

| **CAUSE (S)** | **Likelihood** |
|---|---|
| 1. Not adapted equipment / Poor coordination between designer, owner engineer and contractor / Not adequate engineering / Stoppage of funding / Delay on fuel delivery / Increase of fuel cost. | Unlikely |

| **IMPACT (S)** | **Evaluation** |
|---|---|
| 1. Over delay / Over cost. | Minor |

| **Risk** |
|---|
| 🟩 |
| **ADOPTED** 🟩 |

**Comments**

**Comments**