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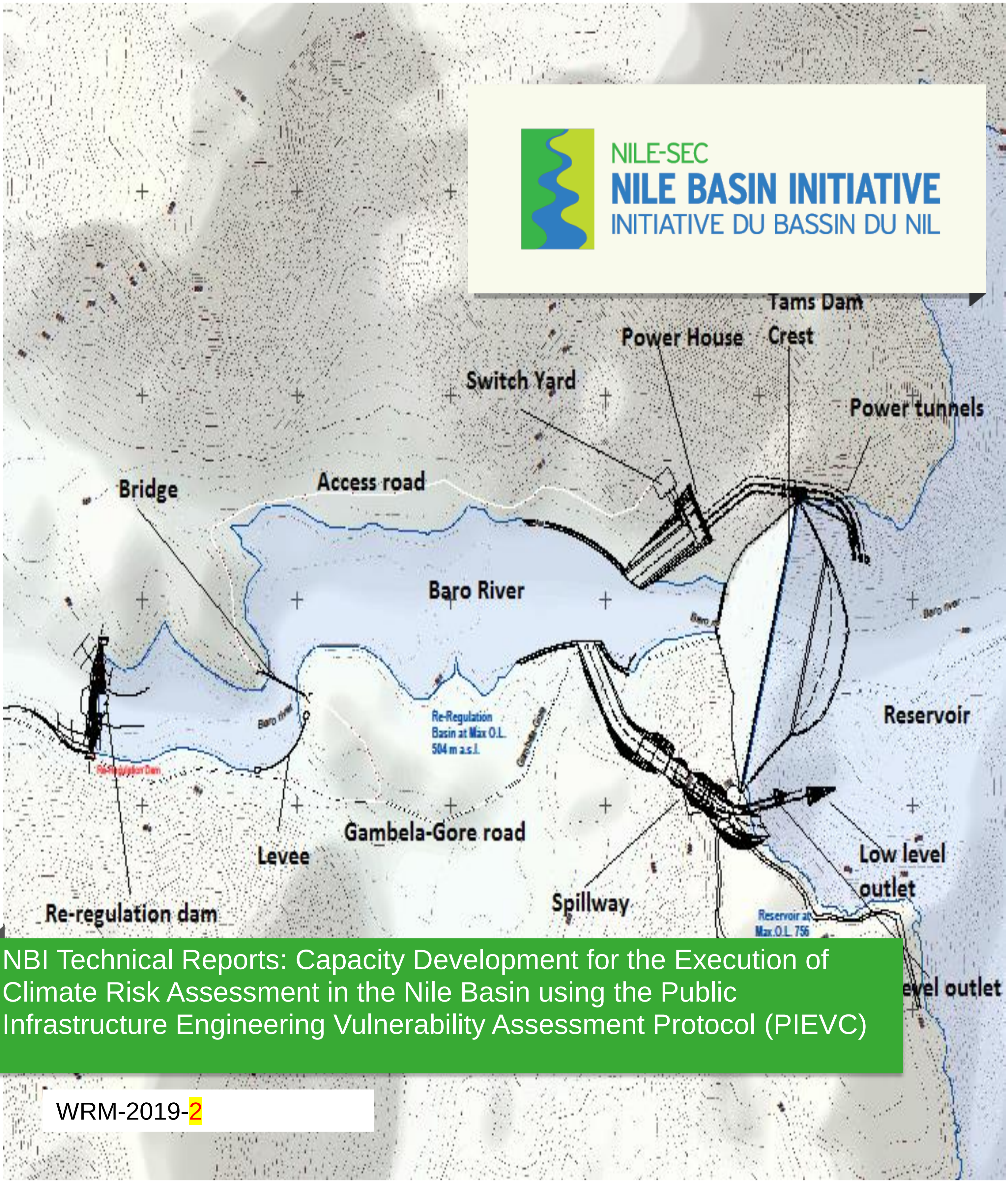

NBI Technical Reports: Capacity Development for the Execution of Climate Risk Assessment in the Nile Basin using the Public Infrastructure Engineering Vulnerability Assessment Protocol (PIEVC)

WRM-2019-2

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Document Sheet

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The purpose of the technical report series is to support informed stakeholder dialogue and decision making in order to achieve sustainable socio-economic development through equitable utilization of, and benefit from, the shared Nile Basin water resources.

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List of Abbrevation and Acronyms

Abbrevation	Description
CFRF	Concrete Faced Rock Fill Dam
CORDEX	Coordinated Regional Climate Downscaling
ENTRO	Eastern Nile Technical Regional Office
FEWS NET	Famine Early Warning Systems Network
GCM	General Circulation Model
GHG	Green House Gas
IPCC	Intergovernmental Panel on Climate Change
KNMI	Royal Netherlands Meteorological Institute
NBI	Nile Basin Initative
NELSAP	Nile Equatorial Lakes Subsidiary Action Program
PIEVC	Public Infrastructure Engineering Vulnerability Committee
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RCA4	Rossby Centre Regional Atmospheric Model
RCC	Roller Compacted Concrete
RCP	Represenative Concentration Pathway
SMHI	Swedish Meteorological and Hydrological Institute

EXECUTIVE SUMMARY

This report provides climate risk assessment of Borenga Multipurpose Dam which is found in Equatorial Nile region of the Nile River Basin. Future climate change is expected to potentially affect water infrastructure in the Nile Basin. Hence climate vulnerability assessment was carried out using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol. The PIEVC engineering protocol is a step-by-step process to conduct an engineering vulnerability assessment on infrastructure due to climate change. The PIEVC protocol is derived from standard risk management methodologies tailoring climate change vulnerability and it has been applied in more than fifty (50) vulnerability assessments to date. The PIEVC Protocol involves five (5) steps namely project description, data gathering and sufficiency, risk assessment, engineering analysis and conclusions and recommendations.

The climate vulnerability assessment show that Borenga Multipurpose dam is expected to withstand future climate events. The main dam structure is determined to withstand future flood conditions as result of climate change. However, the dams will be highly vulnerable to the effects of climate change during construction period. Temporary structures such as cofferdams and diversion channels which are used during the construction of the main dam are usually designed with low return period and constructed with cheap available materials. The assessment determined that probability of occurrence flood events will increase in the future and these temporary structures can collapse and the construction of the dams can be affected. The assessment ascertains that Borenga Dam will be affected by future climate change. The effect will be on spill way components such as radial gates and stilling basins. The assessment investigated the reservoirs of Borenga Dam and the hydropower and irrigation functions of the reservoir. It found out that the reservoir and the functions of the Dams will not be significantly affected, and the risk of climate change is very low.

As indicated above Borenga Multipurpose dams are vulnerable during the construction period. Hence the main recommendation provided by the assessment team is to design coffer dams for longer return period considering climate change, check the current coffer dams and diversion

structures against project climate and consider other diversion methods during final design of these infrastructure.

The report also investigates the fact that the vulnerability assessment conducted has limitations. Some of the limitations include: the use of limited climate model data for future climate projection, the uncertainty in the assessment of the likelihood and magnitude of climate-infrastructure interactions and the difficulty in converting hydrological information to a form that could be applied to the PIEVC.

1.0 Introduction

1.1 Background

Every year, emerging and developing countries invest billions of euros in infrastructure projects. Future climate scenarios are rarely systematically considered, resulting in high risks for damages and bad investments (OECD, 2016). In 2015, insurance companies paid USD 27 billion in compensation for damages caused by natural disasters (OECD, 2016). Of this amount, 94% were caused by extreme weather events which are expected to increase due to climate change (Munich Re, 2016). Protecting durable infrastructure against the effects of climate change requires customized planning processes as well as a range of services making climate information more accessible and usable for decision-makers.

Many countries, at present, lack such climate services - particularly in the context of infrastructure planning. Even when climate services are available, relevant decision-making processes do not always make best use of these services (USAID, 2012) as there are no such requirements in the planning process or there is a lack of awareness among decision-makers. The result is that new infrastructure projects are planned without consideration of future climate change, thereby increasing their vulnerability. The failure of critical infrastructure systems, such as water and energy supply, due to climate extremes can acutely reduce a population's adaptability and can have significant impacts on economies.

Another issue is the lack of knowledge about climate vulnerability of existing infrastructure. In a national survey, the operators of infrastructure in the UK, for example, could in many cases neither state how their infrastructure is affected by climatic conditions, nor which measures to use to adopt to climate change (UK Committee on climate change, 2014). However, this information is essential for effective climate risk management. Increasing the resilience of infrastructure through the enhanced use of climate services, therefore, constitutes an important component in the process of national adaptation planning (NAP).

Activities and initiatives to promote climate services, to date, have often been limited to either the supply side (the creation of climate services) or their embedding in planning processes. Frequently, there is a lack of an integrated approach linking relevant contributors, including providers of climate services, decision-makers and engineers.

The Enhancing Climate Services for Infrastructure Investments (CSI) project is filling this gap by supporting government agencies and decision-makers in the use of climate services for planning of resilient infrastructure. One aspect of efforts working towards this objective, has included adapting institutions and technical processes to enable countries to access climate information, advisory services and products and use these for their infrastructure planning. A capacity development component of these efforts has focused on completing a technical risk analysis of selected infrastructure. The NBI project, which is summarized in this report, has been focused on climate vulnerability assessments of the Borenga Dam project proposal, a component of the Mara Valley Project.

1.2 Objective

The overarching objective of the climate vulnerability assessment of the Borenga Multi-purpose Dam has been to ensure that climate related vulnerabilities in the designs and planned operations of these projects are identified and measures/actions to mitigate these risks are advanced in the design and planning process.

1.3 Scope

The NBI climate risk assessment has been focused on water resources infrastructure. The NBI has carried out several studies on water resources and developed tools for decision-making. The climate risk assessment has used the outputs of these studies. The assessment was completed with close coordination and collaboration between NELSAP and ENTRO, two centers of the NBI. The Borenga multi-purpose Dam project is currently in the planning stage. This project has been planned/ designed as a multi-purpose system supporting hydropower generation, irrigation and flood control.

The climate risk assessment included review of both existing and future climate data. Outputs from the climate risk assessment have also been used to support the development of the Nile Basin climate proofing guideline and climate service action plan.

1.4 Implementation process – the focus on Capacity Development

One aspect of the capacity development component of the overarching project, included training on the Engineers Canada PIEVC Protocol for infrastructure climate change risk assessment. This training was provided to the NBI assessment team and supported by experts from Engineers Canada and the global engineering consulting firm Wood Environment & Infrastructure Solutions (Wood).

This training, which also provided the framework for NBI team collaboration for the risk assessment, was conducted over three (3) workshops and additional assessment team meetings over a period of about two years, as summarized below:

- The first climate risk assessment workshop was held in Entebbe, Uganda from October 17-19, 2018. The objectives were; (1) to train and scope the PIEVC application for the two case studies including identification of data requirements and detail preparation of the next workshops; and (2) to enable the NBI assessment team to prepare all the required information for the second workshop and to share and discuss historical and future climate trends of the selected case study sites.
- The second workshop was held in Entebbe, Uganda from November 13-15, 2018. The objectives of this workshop were; (1) to define the infrastructure components and performance responses for the climate risk assessment of the Borenga Multi-purpose dam; and (2) to enable the assessment team to prepare all the required information for the third workshop and obtain an in-depth understanding of the two study developments.
- The third workshop was held in Addis Ababa, Ethiopia from April 8-12, 2019. The objectives were to; (1) review the result of historical climate and climate projections analysis of the Borenga multi-purpose dam; (2) review the results of flood modelling completed for the two watersheds; and (3) and initiate the climate risk assessment.
- The first task team meeting, which consisted of a smaller number of experts, was held May 23-24, 2019 in Addis Ababa, Ethiopia. The specific objectives of this task team meeting where; (1) to review the infrastructure components selected and restructure these components focusing on the services they support; (2) to review and

recommend further improvement on the infrastructure threshold definitions; (3) to define response considerations and scoring methodology; (4) review the probability and scoring methods proposed by PIEVC; and (5) define the climate risk matrix configuration to be employed for the assessment.

- The final, second climate risk assessment meeting was held on October 23-25, 2019 in Entebbe, Uganda. The objective was to finalize the risk assessment and hence was planned and attended by some members of the assessment team. The objectives were; (1) to review climate risk assessment results of Borenga multi-purpose dam which was completed during the first task team meeting and provide rationale for severity values used; (2) identify climate vulnerable components of Borenga multi-purpose dams using the risk assessments findings; and (3) provide recommendations to address the identified climate vulnerable components of the dam.

The NBI assessment team was the main implementing entity which led and completed the risk assessments for two case study sites in the Nile Equatorial and Eastern Nile regions. The assessment team was composed of experts from NILESEC, NELSAP, ENTRO and national experts who are engaged with dam planning, design and operations. The PIEVC protocol was provided by Engineers Canada and guidance on the PIEVC protocol was provided by WOOD. Experts from NILESEC and the Climate Service Infrastructure project facilitated the climate risk assessment workshops. Wood also participated in the development and facilitation of workshops #2 and #3.

The NBI assessment team consisted of three groups, as follows:

1. NELSAP & ENTRO - This group provided data and reports for the Borenga multi-purpose dam. Participants of the group also carried out historical climate analysis for Borenga and presented the results. In addition, they attended the workshops and provided input during the risk assessment of Tams multi-purpose dam.

2. NILSEC - Carried out historical and future climate analysis for the assessments. They actively participated and presented on climate and flood conditions for the case study sites in the workshops.

3. GIZ group- Led the planning and implementation of the risk assessment workshops. Facilitated the workshops and guided the participants in carrying out the risk assessment.

Individual assessment team members are summarized in Table 1.

Table 1 Task Team Members

GIZ	Michael Menker	Niklas Baumert	
NILESEC	Milly Mbuliro	Modathir Zaroug	Yohannes Gebretsadik
NELSAP	Maro Andy Tola John Situma	Mwasiti Rashid Martin Okirya	Sami Osman Arsene Mukubwa
ENTRO	Michael Abebe	Azeb Mersha	Deksyos Tarekegn
National experts	Belete Birhanu Surafel Mamao	Mohammed Abdulkadir	Leulseged Abayneh

Figure 1 Risk assessment workshops photos

2.0 Case Study Selection

2.1 Eastern Nile Region

The following approach was used in selecting and implementing the climate risk assessment in the Eastern Nile Region.

- A list of candidates planned projects were collected from the Eastern Nile Technical Regional Office.
- Two projects were screened from the Eastern Nile regions following the criteria developed during the first risk assessment workshop and provided in Table 2.
- The planned water resource project which obtained the highest score was selected for climate risk assessment. This was done by the participants during the first climate risk assessment workshop. The selection was made after the participants had received their initial training on the PIEVC climate risk assessment methodology.
- Water resource specialists of ENTRO and NELSAP, and Dam Experts from the Eastern Nile and Equatorial Lake Regions, actively participated during the case study selection process.

Table 2 Criteria for Selection of Water Infrastructure for Climate Risk Assessment

NO.	CRITERIA	DESCRIPTION
1	Relevance	• Climate risk assessment seems to be of relevance for the project (e.g. for bank request and stakeholder's engagement etc.)? • Is it relevant to carry out climate risk assessment on the infrastructure in terms of counteracting possible climate change? Is the water resource sensitive to climate change and climate variability?
2	Implementation period (Readiness)	• Is it feasible to carry out the risk assessment this year?
3	Water infrastructure type	• Does the infrastructure have reservoir? Or is it a River diversion? Infrastructure with a reservoir will allow to study the risk of climate change on irrigation, hydropower and flood control • Is the water infrastructure Multipurpose? With multi-purpose infrastructure it is possible to assess climate risk on hydropower, irrigation, flood control etc.
4	Synergy with ongoing process	• Is there a motivated group from NELSAP, ENTRO or countries working on the project and it will not be difficult to add the risk assessment (i.e. no complications expected)? • Are project staff available? Are they willing to participate in climate risk assessment?
5	Availability of project documents, data, processes	• Is there an existing planning process to piggy back the climate risk assessment onto? • Is there a project document? Is there data and information on climate of the project site, dam components, reservoir etc. • What is the exact planning status? What plans have been completed (pre-feasibility, feasibility, design, etc.) • Is there a water resources planning model incorporated in the project?
6	Representativeness	• Is the site representative of a certain hydrological zone or design problem in the Nile Basin? Can results be extrapolated to other similar hydrological zones or similar cases based on the findings of the study?
7	Ownership by project owners	• Can the dam owner take the climate risk assessment as an important component of the planning process? Can they

		take the output of the study for further planning or take appropriate corrective measures? • If the infrastructure is at planning stage, do we have personnel who can provide information on technical and administration aspects of the dam and reservoir?

In the list of candidates planned projects, ENTRO had proposed the Tams and Karadobi Water Resource development projects. During the first climate risk assessment workshop, the Tams Dam project was selected to be used as a case study for the climate risk assessment exercise.

2.2 Nile Equatorial Lakes Region

The following approach was used in selecting and implementing the climate risk assessment in the Nile Equatorial Lakes Region.

- A list of candidates planned projects were collected from the Nile Equatorial Lakes Subsidiary Action Program (NELSAP). These included:
    - Kabuyanda Multi-Purpose Water Resources development project in Uganda;
    - Mara Valley Irrigation Development Project with Borenga Dam component in Tanzania;
    - Ngono Valley Irrigation development Project in Tanzania;
    - Sio-Sango Multi-Purpose Water Resources development project in Kenya; and,
    - Nyimur Multi-Purpose Water Resources Development project in Uganda.

- Two projects were screened from the list above following the criteria developed during the first risk assessment workshop (ref. Table 1).

- The planned water resource project which was assigned the highest score was selected for climate risk assessment. This was done by the participants during the first climate risk assessment workshop. The selection was made after the participants had received their initial training on the PIEVC climate risk assessment methodology.

- Water resource specialists from ENTRO and NELSAP, and Dam Experts from Eastern Nile and Equatorial Lake Regions, were actively participated during the case study selection process.

NELSAP is preparing the first four projects under the World Bank NCORE-CIWA program. The Nyimur multi-purpose water resources development project is funded through the African Water Facility of AfDB and it already has incorporated a climate change component. During the first climate risk assessment workshop, the Mara Valley Irrigation Development Project with Borenga Dam component in Tanzania, was selected for the climate risk assessment exercise.

3.0 Climate Risk of Intrastructure

The Fifth IPCC assessment report (AR5) (Climate Change, 2014) introduced a concept for understanding risk of impacts from climate change. Accordingly, the IPCC defines risk as the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values.

Risk results from the interaction of vulnerability, exposure, and hazard (IPCC, 2014). The risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left) and socioeconomic processes including resilience action are drivers of hazards, exposure, and vulnerability.

Climatic Change & bio-physical Impacts is defined as the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. The term hazard usually refers to climate-related physical events or trends or their physical impacts.

Lack of Resilience Performance

- **Exposure** is defined as the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

- **Vulnerability** refers to the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Climate risk of infrastructure systems emerges from those mechanisms and processes that create might lead to loss of serviceability and loss of infrastructure assets resulting from (1) climate change and its bio-physical impacts and (2) the lack climate resilience performance (due to lack of coping & adaptive capacity) of infrastructure systems, leading to exposure and overall vulnerability of the system to these bio-physical impacts.

For identifying adaptation options understanding the causal structure of risk and their root causes is essential. For infrastructure systems the causal structure of risk of loss & damage (as a result of lack of resilience performance) can be analysed based on the following causality frames (Compare Figure 7):

- **Risk as the outcome of the lack of capacity for anticipating current and future risks** and vulnerabilities in pursuit of reducing exposure, sensitivity and increasing adaptive capacity.
- **Risk as the outcome of high level of exposure** as a result of the lack of
    - mitigating climate effects (e.g. afforestation upstream to reduce flood run-off speed),
    - anticipatory risk zoning for new investments, and
    - adequately governing retreat in cases where increasing resilience on the spot is no option anymore.
- **The lack of the infrastructure systems to be adequately protected** (e.g. lack of green infrastructure), **to be adequately robust** regarding its physical structure and functionality, **and to be adequately equipped with climate sensitive operational and maintenance procedures** to withstand bio-physical climate impacts.
- **The lack of infrastructure systems to adequately cope with extreme events**, such as performing disaster management and business continuity management in the course and aftermath of climate related physical extreme events, including effective warning and response systems; as well as reconstruction contingencies.

These risk narratives provide entry points for assessing narrative specific causalities that can be searched in unfavourable societal, political, regulative, economic, and environmental framework conditions and contexts in which infrastructures investments are carried out.

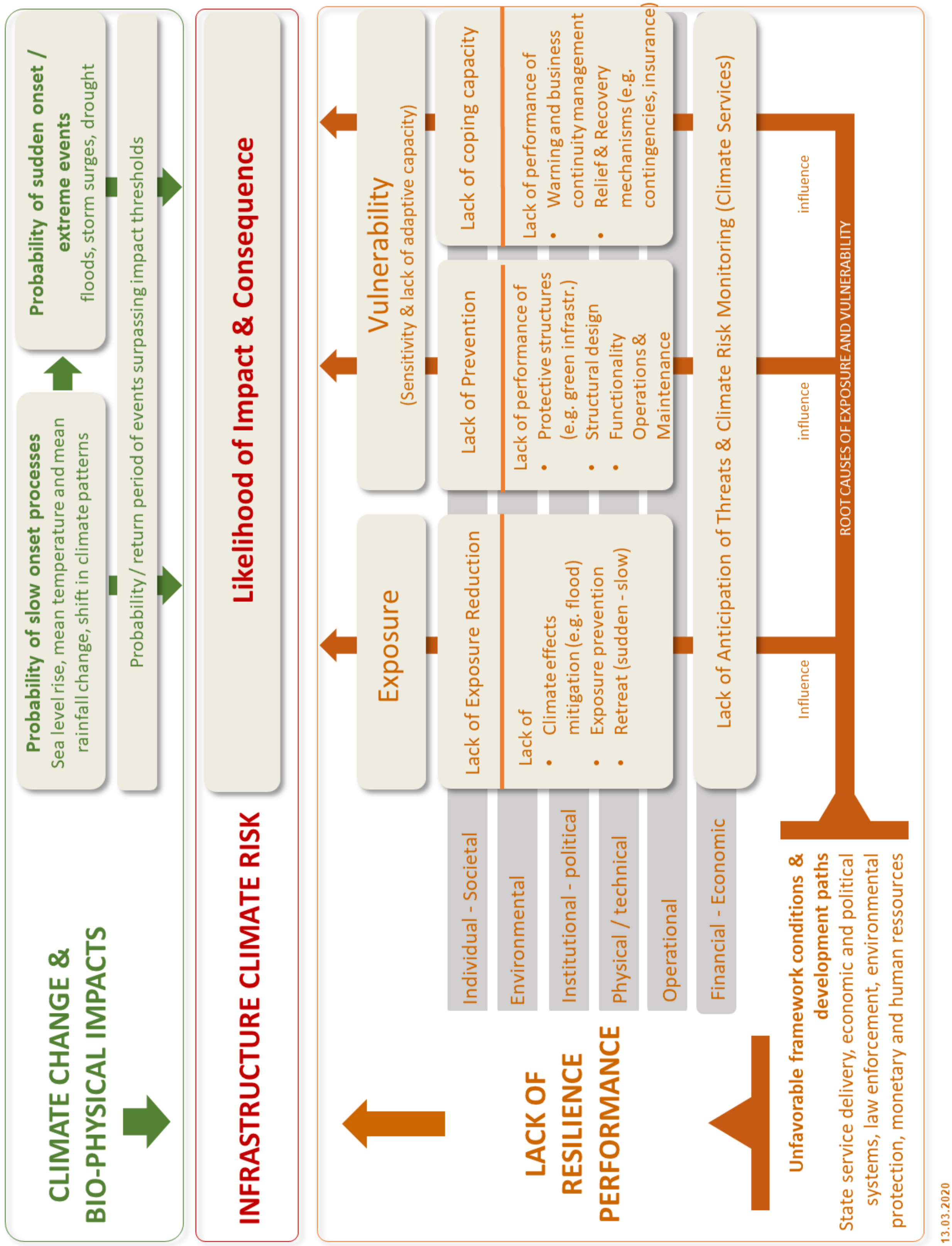

Figure 7 Framework for climate risk of infrastructure (Adapted from Baumert, 2016)

4.0 Methodology for Climate Risk Assessment – The PIEVC Engineering Protocol

The Public Infrastructure Vulnerability Assessment Committee (PIEVC) engineering protocol is a step-by-step process to conduct an engineering vulnerability assessment on infrastructure due to climate change (Engineers Canada, 2013). The PIEVC protocol is derived from standard risk management methodologies tailoring climate change vulnerability and it has been applied in more than fifty (50) vulnerability assessments to date. The PIEVC Protocol involves five (5) steps as illustrated in Figure 2; each of which is described in the following report sections.

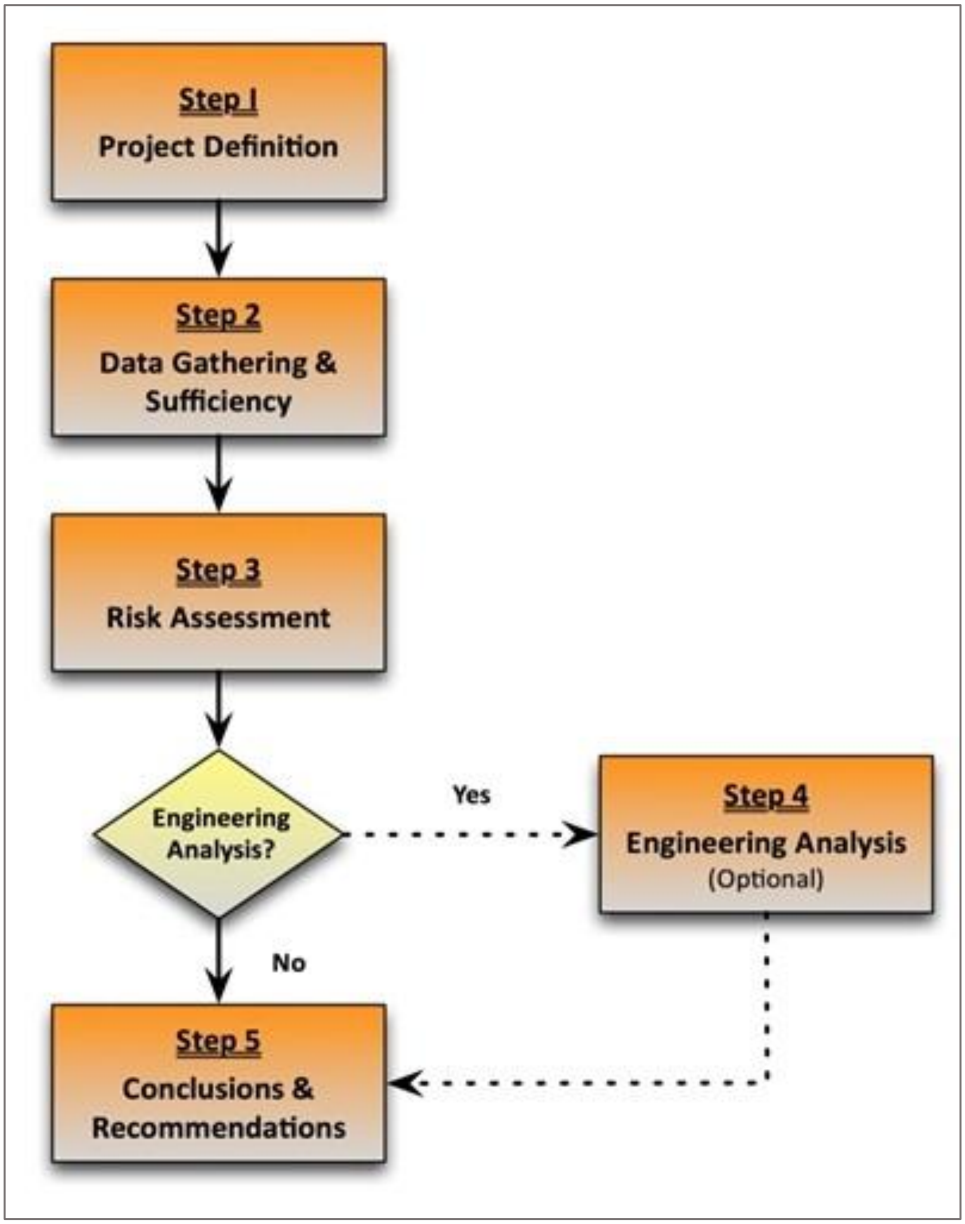

Figure 2 PIEVC Protocol Flow Chart

4.1 PIEVC Protocol Step 1 – Project Definition

Step 1 of the PIEVC Protocol focuses on the development of a general description for the following aspects of the project:

- location of the vulnerability assessment;
- infrastructure of concern;
- historic climate;
- existing loads on the subject infrastructure;
- age of the subject infrastructure;
- other relevant factors; and,
- identification of major documents and information sources.

The outcome from this step is a definition of the boundary conditions for the vulnerability assessment.

4.2 PIEVC Protocol Step 2 – Data Gathering and Sufficiency

Step 2 of the PIEVC Protocol focuses on describing aspects of the subject infrastructure that will be assessed with relevant climate change parameters. Identification of the infrastructure components to be considered for evaluation has focused on:

- What are the infrastructure components of interest to be evaluated?
- Number of physical elements and location(s).
- Other potential engineering / technical considerations.
- Operations and maintenance practices and performance goals.

The second part of this task focused on identification of relevant climate information. Climatic and meteorological data (both existing/historic data, as well as, future projected climate data) has been identified and collected. The objectives of the climate analysis and projections component of this assessment are to:

- establish a set of climate parameters describing climatic and meteorological phenomena relevant to the study location, and;

- establish a general probability of occurrence of each climate phenomena, both historically and in the future.

4.3 PIEVC Protocol Step 3 – Risk Assessment

An engineering vulnerability exists when the total load effects on infrastructure exceed the total capacity to withstand them, while meeting the desired performance criteria. Where the total loads or effects do not exceed the total capacity, adaptive capacity exists.

Step 3 of the PIEVC Protocol focuses on a qualitative risk screening exercise serving the identification of hotspot risks, and prioritizing more detailed assessments or engineering Analyses, if required, in Step 4 of the Protocol. Professional judgment and experience are used to determine the likely effect of individual climate events on individual physical and operational components and processes of the infrastructure, as well as the impacts of the service the infrastructure is designed to provide. To achieve this objective, the Protocol uses an assessment scoring system to be applied for assigning estimated probability and severity values (0-7) for each potential interaction between to be defined climate event types and infrastructure components in focus.

The Protocol specifies that a Scoring system with values ranging from 0 to 7 be applied to rank both the potential climate events and the estimated response severity. An evaluation of this type is usually completed during a Risk Assessment Workshop which brings together representatives of the infrastructure owner/operator plus other stakeholders.

The objectives of a risk assessment workshop would include:

- learning more about interactions between infrastructure components and weather events;
- identifying anecdotal evidence of infrastructure responses to weather events;
- discussing other factors that may affect infrastructure capacity;
- identifying actions that could address climate effects; and,
- identifying and documenting the local perspective relevant to the subject infrastructure.

4.4 PIEVC Protocol Step 4 – Engineering Analysis

Step 4 of the Protocol is focused on climate/infrastructure interactions requiring further assessment, identified in Step 3. This step is optional and not every assessment or interaction requires engineering analysis to be completed. The needed additional and more focused analysis will assist to further resolve the risk profile of the subject infrastructure. This may include, but is not limited to:

- climate/infrastructure interactions found to be medium risk during Step 3 that generated significant debate amongst team members;
- climate/infrastructure interactions found to be part of a pattern of vulnerability, regardless of the risk assessment score;
- areas where information gaps made Step 3 risk assessment problematic; or,
- areas where additional work would help identify mitigation responses that can be immediately implemented.

Please note that Step 4 has not been included within the scope for the Borenga Dam assessment due to project time and financial constraints.

4.5 PIEVC Protocol Step 5 – Conclusions and Recommendations

Recommendations are developed from the work completed in the previous steps. Generally, the recommendations fall into five major categories:

- remedial action is required to upgrade the infrastructure;
- management action is required to account for changes in the infrastructure capacity;
- continue to monitor performance of infrastructure and re-evaluate later;
- no further action is required; and,
- there are gaps in data availability or data quality that require further work.

Additional conclusions or recommendations may be identified regarding the veracity of the assessment, the need for further work, or areas that were excluded from the current assessment.

5.0 Climate Risk Assessment of the Borenga Multi-Purpose Dam

5.1 PIEVC Protocol Step 1 - Scope the climate risk assessment and the system of interest

In this step, the overall decision-making context of the risk assessment is explored, including the definition of global project parameters and boundary conditions for the vulnerability assessment of the Borenga multipurpose dam development. This step included identifying the infrastructure, climate factors, time frame and geographical considerations relevant to the risk assessment.

5.1.1 Scope

The Borenga project's main purpose is to provide water for the Mara valley irrigation development project which has a total area of 6,900 ha. A feasibility study for the dam has been completed, however, a climate change impact or risk has not been considered in the design. To rectify this, the Borenga multi-purpose dam and reservoir were assessed for vulnerabilities to the potential impacts of future climate conditions. The results can inform decision to include climate resilience considerations in the detail design stage prior to implementation, although detail design for the irrigation scheme has already been completed. Figure x provides orientation on the overall context of the risk assessment embedded within a climate risk management process in the preparation of infrastructure projects

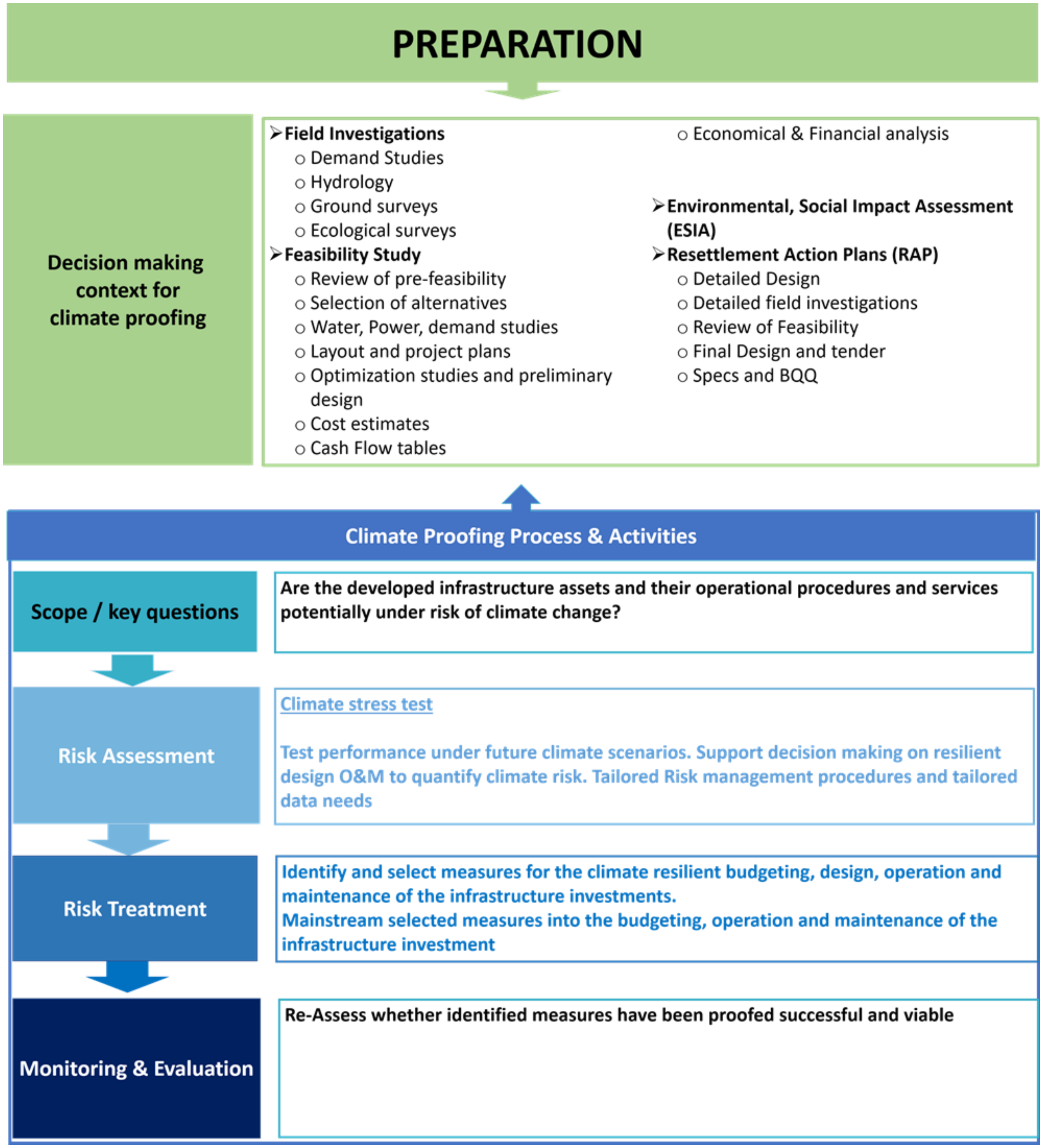

Figure x: Decision making context of the climate risk assessment based on the NBI Guideline for Climate Proofing of Infrastructure Investments

5.1.2 Geographical setting of the Borenga Dam – the Mara Valley and catchment

The development site is situated in Tanzania (ref. Figure 5) and the catchment area to the dam includes lands in both in Tanzania and Kenya.

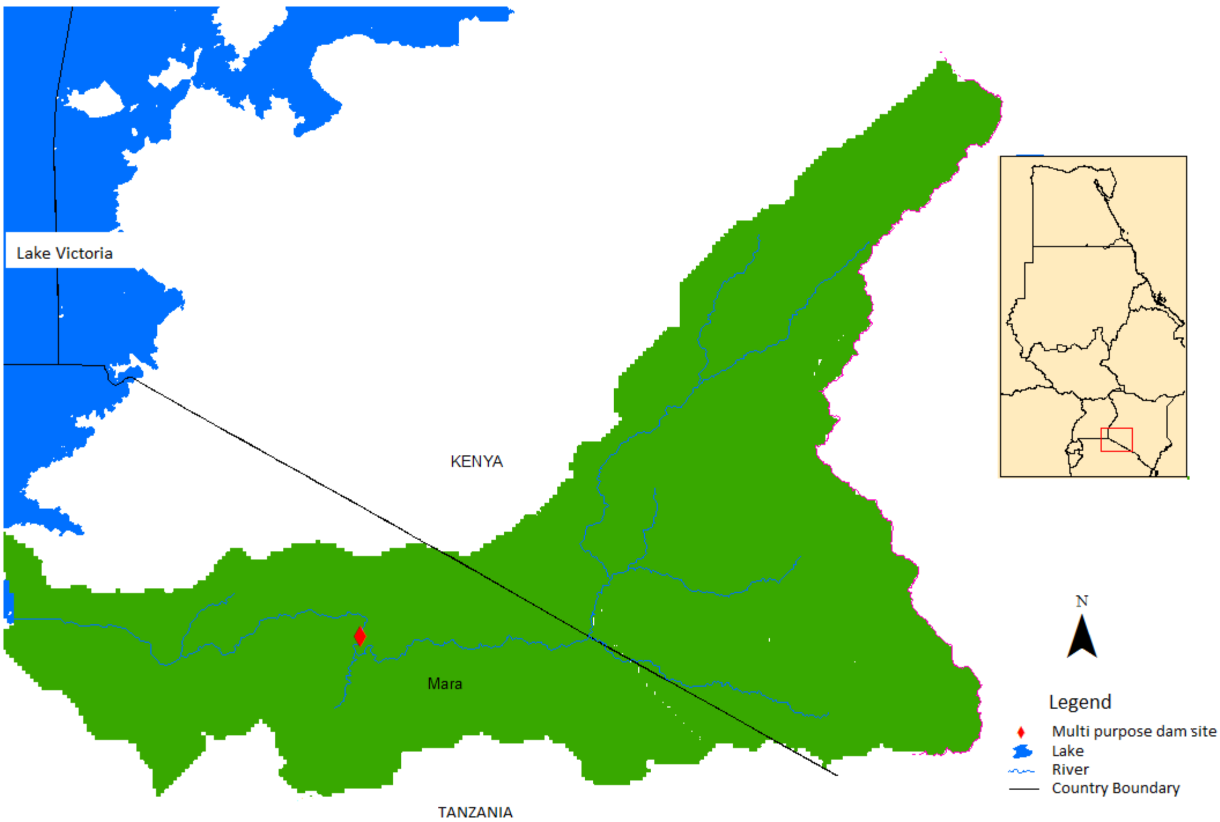

Figure 3 Location of Borenga Dam Development

5.1.3 Key definitions and design parameters of Borenga Dam according to feasibility study

According to the design report of the Mara valley project, Borenga dam is a rolled lean-concrete gravity dam with concrete gravity spillway. Borenga dam has a total height of 21 m and total length of 652.6 m. The total width of the crest is 4.70 m including a road with a width of 3.5 m, two pavements each with 50 cm with and 20 cm crest wall.

The main parts of the Borenga dam consist of gated spillway on the original river water course; the free overflow spillway, located to the right of the gated spillway, partially on the original watercourse; the intakes section, located to the left of the gated spillway; the left and right side hard-fill (lean RCC) gravity dam sections located at the two flanks; a short retaining wall at the far end of the right hard-fill dam section. Layout of the dam is illustrated in Figure 6.

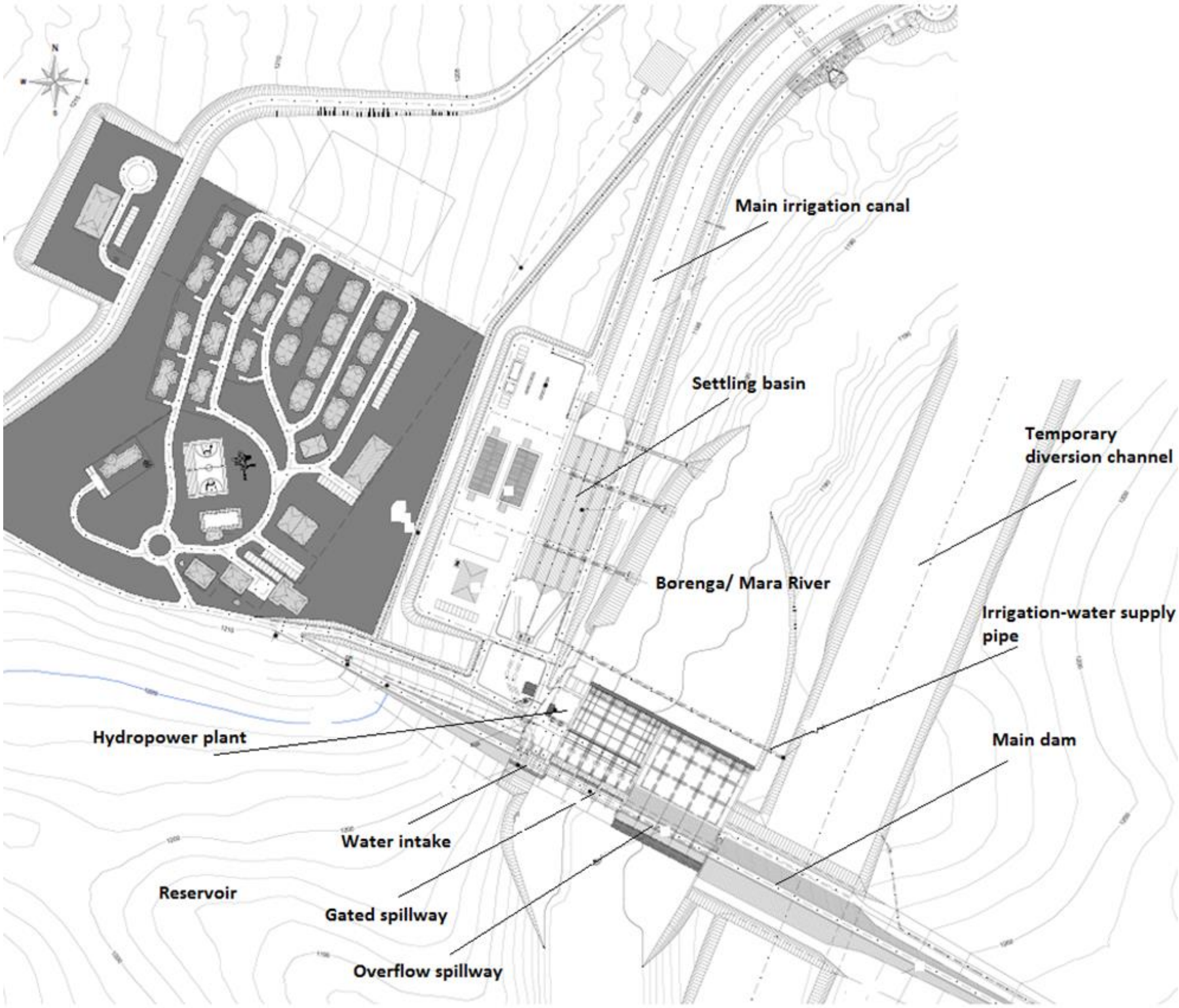

Figure 4 Borenga dam and its components

The middle gate section houses six radial gates that have two function. They serve as the main spillway during high flood and at least once a year they serve as low level outlet for sediment flushing. Due to this reason the gates are placed low above the original riverbed. The overflow spillway provides extra safety and flexibility and reduces the frequency of operation of gates and hence it reduces maintenance costs.

There are two pairs of intakes on Borenga dam. The first pair deliver water to the hydropower plant and the other deliver water to the head works for the irrigation canal. On the left bank downstream of the dam there is a hydropower plant. The irrigation intake is located to the left of the hydropower intakes. The water which flows through the intakes pass through two stilling wells and the calm flow enters a settling tank. The settling tank consists of two parallel tanks so that one can always operate while the sediment accumulated in the other is being flushed back into the Borenga River. Afterwards the flow enters the head regulating reservoir of the canal and then flows through the conveyance canal.

5.1.4 Infrastructure elements utilized during construction period

In the Mara design report a two-phase diversion system is proposed during construction period. In phase 1, the river is diverted through an unlined channel, excavated in rock in the right abutment. The original river-course, at the location of the dam, is isolated by upstream and downstream cofferdams. The upstream and downstream cofferdams have relatively low height with 8 m and 7.5 m respectively.

During phase 1, the gated spillway, free overflow spillway and intake sections of the dam including the hydropower civil works will be constructed. The phase 1, temporary diversion arrangements for Borenga dam will accommodate the 20 years flood of Borenga which is 850 m^3/sec. Construction of the dam components which are liable to flooding can be protected by side-cofferdams. No main cofferdam is required across the river-course.

In phase 2, the river will return to its original watercourse through the openings of the low-level gated spillway constructed during phase 1. In this phase the remaining dam sections will be completed.

5.2 PIEVC Protocol Step 2 – Data Gathering, Sufficiency and Analysis

In this step, further definition regarding the infrastructure and the particular climate effects that are being considered in the evaluation are provided.

5.2.1 Infrastructure Data and design parameters

The minimum inflow design flood (IDF) selected for the dam has 0.1% of annual chance of exceedance. However, it was decided during the design exercise to select an IDF with greater value keeping in consideration the significance of the reservoir in providing the vital community service to the Mara community. Fifty percent of the PMF is adopted as the Spillway Design Flood as an intermediate value between the 1 in 1000 Flood and the PMF. The PMF is estimated to be 8000 m^3/sec. Hence the spillway design flood is 4000 m^3/sec. The spill way is designed with design flood of 2000 m^3/sec with a 1000-year return period. The safety check flood considered is 3000 m^3/sec with a 10,000-year return period.

Selected infrastructure components and their design parameters

Both the dam structures, upstream reservoirs and the functions they support were included in the assessments. A list of the major infrastructure systems and their breakdown into individual components is provided in Table 16.

Table 16: Definition of infrastructure components for Borenga Dam

System	Component	
Infrastructure		
	Gated spillway	Main canal
	Intake for irrigation	Free overflow spillway
	Weir	Powerhouse
	Turbine	Dam crest
	Downstream face of the dam	Water treatment plant
	Upstream face of the dam	Intake for hydropower
	Access road	Power supply facilities
Functional services		
	Water supply	Drought mitigation
	Irrigation	Fisheries
	Hydropower	Transportation service
	Flood mitigation	
Operation		
	Monitoring of water levels	Flushing sediments during low flows
	Releasing flood during high flows	
Construction period		
	Coffer dam	Diversion channel
	Spillway	Embankments
	Access roads	Irrigation structures

Selection of the functional services subject to assessment

According to the Mara design report, the proposed irrigation command area is found in Serengeti and Butiama districts of Tanzania. The areas will be supplied with water using the main conveyance canal which has a total length of 65.7 km. Two cropping patterns are proposed, the first one includes double cropping of paddy on about 44% of the total area. The second cropping pattern proposed is maize-bean rotation on areas which are not prone to the risk of flooding. Most of the irrigation area will be used by small-scale farmers. The irrigation network design is based on a typical farm size of 2 ha which is 200 m in length by 100 m in width.

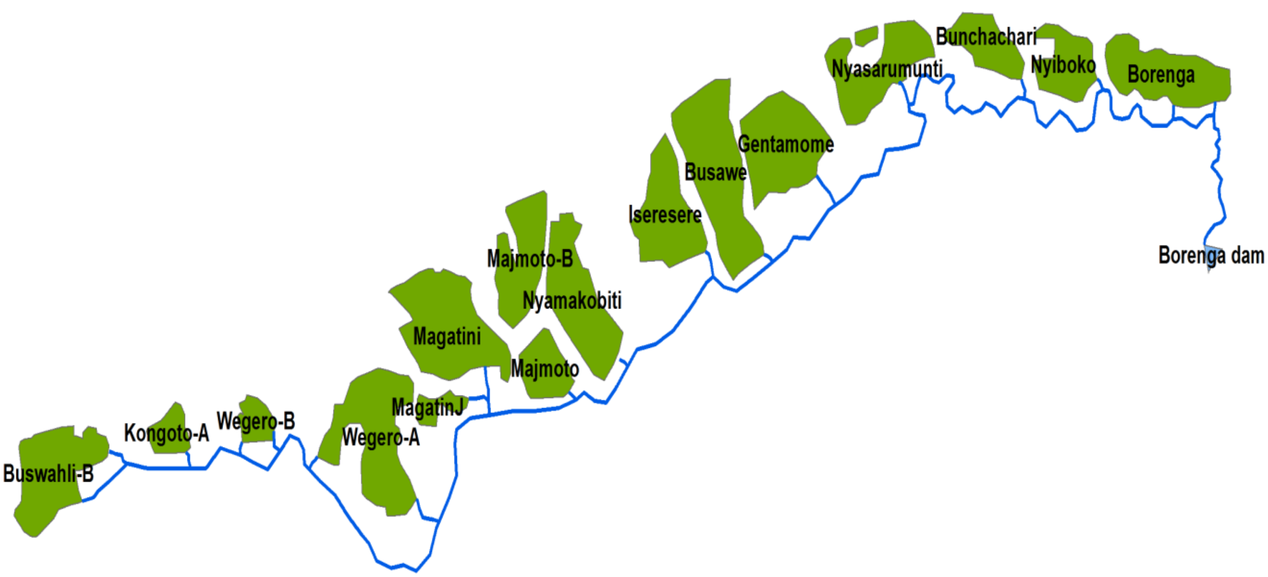

Figure 7 Irrigation layout of Mara Irrigation Project using Borenga dam as water source

The Borenga dam has a hydropower development component. The hydropower plant has a designed installed capacity of 3 MW with annual production of 12.6 GWH. The gross head is 13.75 m with the design discharge of 25 m^3/sec and minimum discharge of 4 m^3/sec. The turbine type is S-type Kaplan.

Selected operational components and processes selected for the assessment

The Borenga dam development will service water abstraction for productive use, the operation of settling tanks, abstraction of water for hydropower, release of environmental flow, effective flushing of sediment from the reservoir on regular basis and safe passage of flood flows downstream. During water abstraction for productive use water is abstracted through the irrigation intake with rate controlled by two sleeve valves and the water flows into the settling tank. The settling tasks are monitored by personnel for sediment levels. When there is high sediment level in the tank, one of the two parallel lines of flow can be stopped and the cylinder valve for release of sediment can be opened.

Abstraction of water for hydropower will be done through the hydro intakes and can be controlled from the powerhouse turbines. Water for environment preferably can be released through the hydro plant. It can also be released through the gated sluice in the rear regulating reservoir. For sediment flushing, the radial gates of the dam should be opened for 30 days every year during the rainy season. The low irrigation and other uses demand can be satisfied by occasional closing of the gates and filing the main canal during flushing. The radial gates with the free overflow spillway should be used for the safe passage of flood.

5.2.2 Data Sufficiency

In the following a short statement on data sufficiency for the risk assessment is provided:

- Data sufficiency related to the infrastructure: The amount of infrastructure and climate data gathered was sufficient for carrying out the risk assessment. However, as the Borenga project is a planned development it was not possible to have a site visit and collect primary data. Borenga has detailed design for the irrigation infrastructure and this provided useful information for the assessment. Sources of information for infrastructure data includes the following documents:
    - Final Feasibility Report of Borenga Dam (G. Karavokyris & Partners, 2014)
    - Design Report of Mara Valley project (G. Karavokyris & Partners, 2018)
    - Nile Basin Initiative Strategic Water Resources Analysis: Current and projected demand and water use in the Nile Basin (Nile Basin Initiative, 2017)
    - Nile Equatorial Lakes Multi-Sector Investment Opportunity Analysis Analytical Framework Report (BRL ingenierie, 2012)

- Data sufficiency related to climate projections: Bias corrected climate projection data was used to understand the climate change pattern in the Borenga watershed. However, this data is limited in scope and is not representative of all the future climate scenarios. To supplement the climate change information, additional data was used from other documents such as the IPCC 5th assessment report, African Chapter (Source)

5.2.3 Definition of Climate and Hydrological Variables

A long list of climate and hydrological variables were proposed during the second assessment workshop and later the task team screened and recommended to focus on high temperature, low temperature and heavy annual rainfall, PMF, 10,000-year flood, 25-year flood. The list of climate and hydrological variables proposed is provided below:

- Probable Maximum Flood
- 10,000-year Flood (safety check flood)
- 1000-year Flood (design flood)
- 5-year Flood (design flood)
- Dead storage availability for sediment
- High Temperature
- Low Temperature
- High Winds
- Lightning
- Sediment
- Hail Tropical cyclones
- Solar radiation
- Humidity

5.2.4 Climate analysis and projection

To the extent possible, data and information from the NBI were used in the development of climate change scenarios for the assessment. Further, additional climate change datasets were collected and processed to generate the necessary information to support the climate risk assessment.

5.2.4.1 High Temperature

The measure of high temperature was defined as the number of days in a given year when the maximum temperature is greater than 38 °C.

a) Historical climate

Observed temperature data from the early 1970's to early 2000 was obtained from three stations in the Mara catchment (i.e. Governor's camp, Kichwa Tembo Camp and Keekorok stations) were used for analysing high temperature.

Based on the findings summarized in Table 17, 0 days per year with a maximum temperature greater than 38°C was compared to the established ranges in Table 5 and subsequently attributed a probability score of "1", with an "improbable or highly unlikely" chance of occurrence.

Table 3 High Temperature Results for the Period 1973-2008

Description	**Days/Year**
Number of days with a maximum temperature > 38°C	0
Number of days with a maximum temperature > 29°C	0.18
Number of days with a maximum temperature > 25°C	0.71

b) Climate projections

Based on the findings summarized in Table 18, 0 days per year with a maximum temperature greater than 38°C was compared to the established ranges in Table 5 and subsequently attributed a probability score of "1", with an "improbable or highly unlikely" chance of occurrence during 2036-2065 and 2066-2095.

Table 4 High Temperature Results for the Periods 2036-2065 and 2066-2095

Description	**Days/Year**
Number of days with a maximum temperature > 38°C during 2036-2065	0
Number of days with a maximum temperature > 38°C during 2066-2095	0

5.2.4.2 Low Temperature

The measure of low temperature was defined as the number of days in a given year when the minimum temperature is less than 10 °C.

a) Historical climate

Based on the findings summarized in Table 19, 0.02 days per year with a minimum temperature less than 10°C was compared to the established ranges in Table 5 and subsequently attributed a probability score of "1", with an "improbable or highly unlikely" chance of occurrence.

Table 19 Low Temperature Results for the Period 1973-2008

Description	**Days/Year**
Number of days with a minimum temperature < 10°C	0.02
Number of days with a minimum temperature < 5°C	0

b) Climate projections

Based on the findings summarized in Table 20, 0 days per year with a minimum of temperature less than 10°C in Mara area for the two periods (2036-2065 and 2066- 2095) was compared to the established ranges in Table 5 and subsequently attributed a probability score of "1", with an "improbable or highly unlikely" chance of occurrence.

Table 20 Low Temperature Results for the Periods 2036-2065 and 2066-2095

Description	**Days/Year**
Number of days with a minimum temperature < 10°C during 2036-2065 and 2066-2095	0
Number of days with a minimum temperature < 18°C during 2036-2065	0.07
Number of days with a minimum temperature < 18°C during 2066-2095	0.01

5.2.4.3 Heavy Annual Rainfall

Heavy annual rainfall was defined as the number of years that experienced an annual rainfall total exceeding 900 mm.

a) Historical climate

Based on the findings summarized in Table 21, 0.65 days per year with a heavy annual rainfall was compared to the established ranges in Table 5 and subsequently attributed a probability score of "4", with a "Moderate/possible" chance of occurrence.

Table 21 Heavy Annual Rainfall Results for the Period 1973-2008

Description	**Days/Year**
Number of days with annual rainfall > 900 mm at Keekorouk	0.65
Number of days with annual rainfall > 900 mm at Kichwa Tembo camp	0.41
Number of days with annual rainfall > 900 mm at Governors camp	0.67

b) Climate projections

Based on the findings summarized in Table 22, 0.89 years with annual rainfall greater than 900 mm in Mara area for the period 2036-2065 and 0.95 days per year for 2066- 2095 was compared to the established ranges in table 5 and subsequently attributed to probability score of "6", with "probable" chance of occurrence.

Table 5 Heavy Annual Rainfall Results for the Periods 2036-2065 and 2066-2095

Description	**Days/Year**
Number of years with annual rainfall > 900 mm during 2036-2065	0.89
Number of years with annual rainfall > 900 mm during 2066-2095	0.95

5.2.4.4 Hydrological parameters

A list of hydrological parameters was developed for Borenga during the second risk assessment workshop considering climatic and meteorological phenomena relevant for assessing climate risk for water infrastructure. The development of the list also considered the geographical region of the Borenga dam and associated climate and hydrological variables. The list was then shared with the risk assessment team for further refinement. Since the risk assessment is considering planned dams rather than existing dams, the task team members agreed to focus on design hydrological parameters rather than emphasizing on climate parameters. The team also emphasized that due to the location of the dams (i.e. tropical region of Africa), the direct impact of climate variables is minimal.

The assessment team members identified the hydrological parameters, with the associated definitions, summarized in Table 24 for the Borenga development.

Table 6 Summary of Hydrological Parameters

Hydrological Parameter	**Definition**
Extreme flood (Probable Maximum Flood)	Flow of 8,000 m^3/sec
Safety check flood (10,000 year flood)	Flow of 3,000 m^3/sec
Design flood	Flow of 2,000 m^3/sec
5 year flood	Flow of 550 m^3/sec
Dead storage availability	less than 11 mt/year sediment load in Boregna's reservoir.

5.3 PIEVC Protocol Step 3 – Risk Assessment

5.3.1 Methodology

Following the project definition, and data gathering and sufficiency steps, the third step in PIEVC protocol is the risk assessment. In this step, the infrastructure's response to the climate parameters is identified. Infrastructure and climate/flood interactions that are identified as vulnerable and that require further analysis are identified. To determine a value for the risk associated with an interaction between an infrastructure component and a climate/flood related event, the protocol dictates that the probability of occurrence is multiplied by the severity of the impact to determine the overall risk value.

To develop a risk value for each infrastructure-climate interaction, scales of 0 – 7 are established for the probability of the interactions occurring and the severity resulting from the interaction. For the severity of impacts scale, the protocol provides two methods; D and E as summarized in Table 13. Method E has been selected for this assessment. Method E has been selected based on non-numerical criteria, which merged well with Step 3 of the PIEVC protocol since it is more qualitative in nature than quantitative. Again, the assessment team considered that the numerical scales provided in the alternative methods would require a level of precision and accuracy that could not be supported by available data regarding climate probability.

A spreadsheet was developed that was comprised of a header row for relevant climate/hydrological events. The title column consists of the relevant infrastructure systems and component. The title column of the matrix was populated with the list of infrastructure systems and components documented in Table 3. The header row of the matrix was populated with the list of climate and hydrological parameters documented in Sections 5.2.2.5 and 5.2.2.6. Under each climate parameter, title sub-columns were created as follows:

- Y/N – Relevant or not relevant for further consideration
- P – Probability of the occurrence of the parameter/event
- S – Severity of the interaction, given that it has occurred
- R – Risk

Table 7 Severity Methods for Climate Risk Assessment

Scale	Severity	
	Method D	**Method E**
0	No effect	Negligible or Not Applicable
1	Measurable 0.0125	Very Low / Unlikely / Rare / Measurable Change
2	Minor 0.025	Low / Seldom / Marginal / Change in Serviceability
3	Moderate 0.050	Occasional Loss of Some Capability
4	Major 0.100	Moderate Loss of Some Capacity
5	Serious 0.200	Likely Regular / Loss of Capacity and Loss of Some Function
6	Hazardous 0.400	Major / Likely / Critical / Loss of Function
7	Catastrophic 0.800	Extreme / Frequent / Continuous / Loss of Asset

The matrix cells under the 'P' column were populated by assessment team members informed by the climate analysis carried out and discussed in the workshops. The cells under the 'S' column were populated using engineering judgement and the results of the workshop, where participants, including dam designers and operators, with local knowledge of the infrastructure worked together to estimate the severity of impacts scoring for the identified infrastructure-climate interactions using the scale factors provided in Table 13. The Risk for each infrastructure-climate interaction was calculated as the probability of the occurrence of the parameter/event (P) multiplied by the severity of the interaction, given that it has occurred (S).

In order to support the risk assessment of infrastructure components under the impacts of climate and hydrological factors, risk tolerance thresholds were established based on the PIEVC Protocol guidelines (Table 4-6). As adopted for this assessment and outlined in Table 14, high risks ($R > 36$) require a considerable response in the detailed design phase. In contrast, a low risk level ($R < 12$) needs not immediate actions. Medium risks ($12 \leq R \leq 36$) should also be taken into account during the detailed design phase. These risk tolerance thresholds were reviewed by the NBI assessment task team, and it was agreed to employ these thresholds for the Tams multi-purpose project vulnerability assessment.

Table 8 Risk Tolerance Thresholds

Risk Range	Threshold	Response
< 12	Low Risk	No immediate action necessary
12 – 35	Medium Risk	Action may be required Engineering analysis may be required
> 36	High Risk	Immediate action required

However, in some special cases, infrastructure components with the low risk scores still need to be considered, including: the very high severity and the very low probability and vice versa (i.e., the very low severity and the very high probability). For example, although tornado has a very low probability, it is expected to have a very high severity, thus it is necessary to be considered to mitigate the damages. In contrast, water level or salinity intrusion usually have a very low severity for the pillars or lock head in a short-term period. However, due to the very high probability, they may cause physical abrasion and corrosion for concrete or metal in the long-term period, resulting in damages of these components. Therefore, these interactions also need to be considered.

5.3.2 Risk assessment summary

The final risk assessment matrice for Borenga Multipurpose dam is provided in Appendix 1. As it is the case for Tams Multipurpose Dam, the assessment team didn't see the importance of dwelling on defining response consideration during the risk assessment. Discussions were held on the methodology of the risk assessment and agreement was reached first to map climate/flood variables vs infrastructure components and then provide qualitative assessment for probability and severity for interaction which are identified to have low, medium and high risk. During the mapping exercise it was indicated that it should not only the design flood, but the consequence should be considered.

The assessment team debated the importance of carrying out risk assessment for current time and agreed only to focus on future time. The reason provided were: 1. since the task team is assessing planned dam and the dam is designed using historical climate, there is no value addition by carrying out climate risk assessment for current period; 2. In addition the dam are at planning stage, which indicate that the designers have the opportunity to include additional climate and flood information in producing final design documents. For existing dam, it is recommended to do historical assessment and evaluate the threshold, review design parameters and compare it with current conditions. For planned dams it is difficult to evaluate as baseline information is non-existent.

The following points summarize the risk assessment findings for the Borenga multi-purpose dam. The risk assessment results are provided under five main headings 1. Infrastructure, 2. Operations 3. Functional Services 4. Construction Period and 5. Other Systems.

- A total of 104 climate|hydrology/infrastructure interactions were identified
- The assessment identified:
  - Seventy-two (72) interactions as low risk for future conditions
  - Thirty (30) interactions as medium risk for future conditions
  - Two (2) interaction was identified as high risk for future conditions
- Forty-seven (47) interactions were relevant for further consideration. These interactions were selected because they were considered to have potential risk.

The risk assessment revelled that hydrological parameters interact more with the Dam infrastructure and functional services than climate parameters. In particular, the 5-year flood (550 m3/sec) which is used for the design of coffer dam during construction is found to be a major risk variable in the development of Borenga Multipurpose Dam. The 5 years flood is expected to have high probability of occurrence. This flood is expected to affect diversion channel, coffer dam, spillway, embankments and irrigation intake.

The 10,000-year flood (3,000 m3/sec) is expected to interact with the dam components mainly the radial gates and stilling basin. Although the probability of occurrence of the 10,000-year flood is expected to be low, it is determined that the severity will be high. This flood is expected to affect water treatment plants, tail race riprap and personnel operation.

The interactions of hydrological and climate parameters with the dam infrastructure and services it provides, and its effects are provided in detail below for the five main components:

1. **Physical structures**

- Dam crest
    - Overtopping lead to dam break
    - Embankment dams have problem of overtopping

- Instruments
    - Not related to the flood but the effect relates to temperature and wind

- Spillway
    - Damage from upstream to downstream part of the spillway
    - Water pressure can make the gate fail
    - Spillway might lose functionality
    - It is expected that more flow to come out of the spillway due to flood
    - There is a possibility that it may lead to dam overtopping
    - The severity is somehow reduced because of alternative

- Powerhouse
    - Tail race water will be formed due to backwater from the River and spillway
    - Access tunnel might not be affected that much

2. **Construction period**

- Design of coffer dam is not sophisticated
- Coffer dams are usually constructed with nearby available material
- Excavation and water filling problem
- Lots of work and expense
- Erosion of tunnels
- Reduction of functionality of tunnel especially if structure is for function such as irrigation
- Structural design is not that important for coffer dams
- If coffer dam is taken away, it will have significant impact during the construction of the main dam

3. **Functions**
    - No effect on irrigation function
    - High flows will affect gates
    - Due to high water at tail race pressure difference will be created and there is a possibility that turbines will be shut down and hence reduction in power generation
    - Since irrigation canals are designed with low flow, they will be affected
    - As result of more water release, there is a possibility of infrastructure and property damage
    - Navigation period will increase as result of availability of water in the river
    - Navigation on the reservoir will be affected
    - Navigation of small boats will be affected
    - From experience, Tams is used for navigation during high floods. Hence the function is ok during high flood
    - However, with stored water in the reservoir navigation will be affected.
4. **Operation**
    - Staff prefer to stay in safe area during flood and dam operation will be affected
    - Routine activity of operators will be affected
    - Loss of life can happen due to flooding
    - Telephone service can be disrupted
    - Telemetry and data transmission will be disrupted
5. **Other systems**
    - Power backup is usually within the powerhouse so minimal effect is expected as result of flooding
    - Flooding with have effect on transmission line and substations. Poles for power supply may fall
    - Interruption of construction due to disturbance of power supply might happen
    - Since fire extinguisher is with the powerhouse, minimal effect is expected on it as result of flooding

- Roads to main dam can be affected as result of flooding. This will have a negative consequence on supply delivery. Particularly it will influence supply of hydro-mechanical systems and the completion of dam on planned dates.
- Insurance can help in reducing risk in some cases
- Lack of good road network will have an effect and can increase risk of project implementation

Table 24 Risk assessment findings for the Borenga Dam

Infrastructure Component	Climate or Hydrological Parameter	Probability	Severity	Risk
Infrastructure				
Dam				
Weir	PMF	1	5	5
Gated Spillway	PMF	1	6	6
Dam Crest	PMF	1	7	7
Radial Gates	PMF	1	6	6
Radial Gates	10,000 year flood	2	6	12
Stilling Basin	PMF	1	6	6
Stilling Basin	10,000 year flood	2	6	12
Stilling Basin	Dead Storage Availability - Sediment	3	6	18
Reservoir	PMF	1	5	5
Reservoir	10,000 year flood	2	5	10
Reservoir	Dead Storage Availability - Sediment	3	5	15
Power Supply Facilities	PMF	1	6	6
Power Supply Facilities	Dead Storage Availability - Sediment	3	3	9
Power Supply Facilities	High Temperature	2	4	8
Water Treatment Plant				
Water Treatment Plant	PMF	1	6	6
Water Treatment Plant	10,000 year flood	2	6	12
Water Treatment Plant	Dead Storage Availability - Sediment	3	3	9
Powerhouse				

Infrastructure Component	Climate or Hydrological Parameter	Probability	Severity	Risk
Generators	High Temperature	2	4	8
Tailrace Channel	PMF	1	3	3
Tailrace Channel	10,000 year flood	2	3	6
Tailrace Rip-Rap Erosion Protection	PMF	1	6	6
Tailrace Rip-Rap Erosion Protection	10,000 year flood	2	6	12
External Power Infrastructure				
Switch Yard	PMF	1	4	4
Switch Yard	High Temperature	2	3	6
High Tension Cables	PMF	1	4	4
High Tension Cables	High Temperature	2	4	8
Transmission Towers	PMF	1	4	4
Transmission Towers	High Temperature	2	3	6
Access Road				
Access Road	PMF	1	5	5
Access Road	10,000 year flood	2	5	10
Access Road	High Temperature	2	2	4
Operations				
Personnel	PMF	1	6	6
Personnel	10,000 year flood	2	6	12
Telephone, Telemetry	PMF	1	6	6
Control/Monitoring Systems	PMF	1	2	2
Control Building	PMF	1	3	3
Functions Services				
Flood Mitigation	PMF	1	6	6
Flood Mitigation	10,000 year flood	2	6	5
Transportation Service	PMF	1	5	5
Transportation Service	10,000 year flood	2	5	10
Construction Period				
Diversion Channel	5-year flood	6	4	24
Access Roads	5-year flood	6	4	24
Cofferdam	5-year flood	6	7	42
Spillway	5-year flood	6	6	36
Embankments	5-year flood	6	5	30
Irrigation Structures (intake)	5-year flood	6	4	24
Transportation				

Infrastructure Component	Climate or Hydrological Parameter	Probability	Severity	Risk
Supplies Delivery	PMF	1	6	6
Supplies Delivery	High Temperature	2	3	6

5.4 PIEVC Protocol Step 5 – Conclusion, Limitations and Recommendations

5.4.1 Conclusion

The following general conclusions can be provided regarding the results of the overall study. The Borenga multipurpose dam is primarily planned to provide mainly irrigation water. It is a small dam designed to withstand medium size inflow events. Since the design parameters for the planning and designing of dam are based on historical climate data, it is important to study the potential effects of future climate on the dam and the services it provides. During the study, the infrastructure was broken out into its various components, which includes both the physical dam components, the services the Dam provides, and Dam operations.

Using the protocol to assess the Borenga multi-purpose dam, the assessment team determined that, in general, Borenga Multipurpose dam has the capacity to withstand the projected future climate (i.e. to the 2080s). However, it is noted that the largest potential impact could be during the construction period and on the spillway structure. Due to expected increase in 25 years flood, the increase in flood magnitude can affect the upstream coffer dam and other diversion structures and hamper the construction of the main Dam. The assessment team also determined that the flood can affect the Dam during the operation of the dam. This mainly on spillway structures such as gates and stilling basins.

5.4.2 Limitations

The uncertainty in the assessment of the likelihood and magnitude of climate - infrastructure interactions is a limitation of this study. As outlined in PIEVC protocol Step 3, judgment of likelihood and magnitude were unique to the individuals who took part in the risk assessment workshop. The probability and risk values documented from the workshop are consensus views of likelihood and magnitude and the range of opinions contributes to uncertainty. More specifically: Overall though, the results of this study are based on applying professional judgment to the assessment of the most current information available within the scope of the PIEVC Protocol and can, therefore, be used as a guide for future action to inform the detailed design of the Tams multi-purpose dam development.

Replicating hydrological parameters for the calculation of probability of occurrence of design floods and probable maximum flood was the other limitation of the study. It was difficult to identify the guidelines and methodology employed to calculate these parameters, hence, to arrive at the values of the parameters provided in the design document of Tams multipurpose dam.

5.4.3 Recommendations

The recommendations for the stages of the detailed design, construction drawing design, and operation and maintenance of the infrastructure associated with the Tams developments have been presented based on the results of the risk assessment. Based on the function and characteristics of the main components of the developments, the recommendations generally consider five (5) primary groups as follows. High vulnerabilities were found during the construction period and the recommendations are provided in number 4 below. The 47 vulnerabilities identified in PIVEC step 3 were aggregated into five headings and recommendations were provided. The increase or decrease in vulnerability can only be attributed to the increased or decreased likelihood of the event occurring.

1. **Physical structures**

   Dam Crest

   - Incorporate fuse plug
   - Consider emergency spillway during design
   - Consider watershed management interventions. This relates to allowing physical space for the river flood along the river course
   - Prepare emergency action plan
   - Use climate projections to determine the future PMF to adjust/amend the dam crest design (height)

Dam Instruments

- Use instruments that can withstand the max and min temperature.

Spillway

- Incorporate fuse plug
- Increase resilience of the spillway by increasing the freeboard and making it flexible to adjust to climate change
- Plan for emergency spillway
- Carry out more investigation during the design planning considering climate change
- Check design parameter of the spillway against high floods

Powerhouse

- Keep the design as it is
- Consider backwater protection (e.g. valve)
- Consider enough space for tail water depending on topography

2. Operations

- Establish emergency plan to be used in the event of flooding
- Create awareness about hazard of flooding and safety measures to be implemented during flooding
- As Tams is a big structure, establish wireless communication system which will be used during severe flooding
- Consider satellite for hydrological data transmission

3. Functional Services

- Establish an early warning system for flood protection
- Establish upstream monitoring system
- Evacuation plan should be prepared
- Review emergency plan if it is prepared during the reconnaissance study
- Consider alternative power sources to be utilized during high flood and disruption of power production from the dam
- Try to have robust irrigation infrastructure design considering climate change to avoid damage in the event of high flow

- Consider the design parameter for navigation as a social condition

4. Construction Period

- Design coffer dams for longer return period considering climate change
- Check it with projected climate
- Consider other diversion methods during design of structure for the construction period

5. Other systems

- Consider alternative power supply for safety purposes
- Consider nearby fire extinguishing service
- Consider modern satellite power transmission
- Consider underground cabling for power transmission
- Improve structural capability of transmission lines and substations
- Consider air transport in places where there is poor road network although it requires high cost
- Widen roads to accommodate appropriated vehicle for the delivery of hydro-mechanical parts for the dam
- The delivery of dam supply should be properly planned. For example, avoid rainy season for transportation of heavy hydro-mechanical parts

6.0 References

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Appendix 1 Finalized Risk Assessment Matrices

Borenga multi-purpose dam

Time Period - Future (2080)	Climate and Other Variables and Events																							
Infrastructure Components	**Extreme Flood (PMF)**				**Safety Check Flood (10,000yr)**				**Design Flood (1,000 years)**				**5 Year Flood (550 m3/s)**				**Dead Storage Availability - Sediment**				**High Temperature**			
	8,000 m³/s				**3,000 m³/s**				**> 2,000 m³/s**				**> Q_5**				**Sediment Load (11 MT/yr)**				**days with max temp > 29°C**			
	P Score =			5	**P Score =**			**6**	**P Score =**			**6**	**P Score =**			**6**	**P Score =3**				**P Score =2**			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
Infrastructure																								
Dam																								
Upstream Face of Dam (Concrete Slab)	Y	1	1	1	N				N				N				N				N			
Weir	Y	1	5	5	N				N				N				N				N			
Upstream Face of Dam (Pre-Cast Concrete)	Y	1	1	1	N				N				N				N				N			
Gated Spillway	Y	1	6	6	N				N				N				N				N			
Road	Y	1	6	6	N				N				N				N				N			
Dam Crest	Y	1	7	7	N				N				N				N				N			
Free Overflow Spillway	Y	1	3	3	N				N				N				N				N			
Intake for Irrigation	Y	1	4	4	N				N				N				N				N			
Main Irrigation Canal	Y	1	2	2	N				N				N				Y	3	2	6	N			
Radial Gates	Y	1	6	6	Y	2	6	12	Y	3	6	18	N				N				N			
Radial Gate Bearings	Y	1	4	4	N				N				N				N				N			
Gate Hoist Mechanism	Y	1	6	6	N				N				N				N				Y	2	4	8
Settling Basin	Y	1	6	6	Y	2	6	12	Y	3	6	18	N				Y	3	6	18	N			

Time Period - Future (2080)	Climate and Other Variables and Events																							
Infrastructure Components	Extreme Flood (PMF)				Safety Check Flood (10,000yr)				Design Flood (1,000 years)				5 Year Flood (550 m3/s)				Dead Storage Availability - Sediment				High Temperature			
	$8,000\ m^3/s$				$3,000\ m^3/s$				$> 2,000\ m^3/s$				$> Q_5$				Sediment Load (11 MT/yr)				days with max temp > 29°C			
	P Score =			5	P Score =			6	P Score =			6	P Score =			6	P Score =3				P Score =2			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
Reservoir	Y	1	5	5	Y	2	5	10	Y	3	5	15	N				Y	3	5	15	N			
Storm water Drain	Y	1	2	2	N				N				N				N				N			
Power Supply Facilities	Y	1	6	6	N				N				N				Y	3	3	9	Y	2	4	8
Backup Power Supply	Y	1	6	6	N				N				N				N				Y	2	3	6
Intake for Hydropower	Y	1	6	6	N				N				N				Y	3	3	9	N			
Water Treatment Plant																								
Water Treatment Plant	Y	1	6	6	Y	2	6	12	Y	3	6	18	N				Y	3	3	9	N			
Powerhouse (surface) - Check components																								
Powerhouse Cover	Y	1	6	6	N				N				N				N				N			
Turbines	N				N				N				N				N				Y	2	2	4
Generators	N				N				N				N				N				Y	2	4	8
SCADA System	N				N				N				N				N				Y	2	2	4
Power Tunnel	N				N				N				N				N				N			
Tailrace Tunnel	N				N				N				N				N				N			
Surge Tanks/Shafts	N				N				N				N				N				N			
Gate Valves	N				N				N				N				N				Y	2	2	4
Access Tunnel	N				N				N				N				N				Y	2	2	4
Tailrace Channel	Y	1	3	3	Y	2	3	6	Y	3	3	9	N				N				N			
Tailrace Rip-Rap Erosion Protection	Y	1	6	6	Y	2	6	12	Y	3	6	18	N				N				N			
External Power Infrastructure - Check Location																								

Time Period - Future (2080)	Climate and Other Variables and Events																							
Infrastructure Components	**Extreme Flood (PMF)**				**Safety Check Flood (10,000yr)**				**Design Flood (1,000 years)**				**5 Year Flood (550 m3/s)**				**Dead Storage Availability - Sediment**				**High Temperature**			
	8,000 m^3/s				**3,000 m^3/s**				**> 2,000 m^3/s**				**> Q_5**				**Sediment Load (11 MT/yr)**				**days with max temp > 29^oC**			
	P Score =			5	**P Score =**			**6**	**P Score =**			**6**	**P Score =**			**6**	**P Score =3**				**P Score =2**			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
Switch Yard	Y	1	4	4	N				N				N				N				Y	2	3	6
High Tension Cables	Y	1	4	4	N				N				N				N				Y	2	4	8
Transmission Towers	Y	1	4	4	N				N				N				N				Y	2	3	6
Access Road																								
Access Road	Y	1	5	5	Y	2	5	10	Y	3	5	15	N				N				Y	2	2	4
Operations																								
Releasing floods-high flows Gates	Y	1	6	6	Y	2	2	4	Y	3	2	6	N				N				N			
Monitoring Water Levels (auto)	Y	1	6	6	Y	2	5	10	Y	3	5	15	N				N				N			
Monitoring Water Levels (manual)	Y	1	6	6	Y	2	6	12	Y	3	6	18	N				N				N			
Flushing sediment during high flows	N				N				N				N				N				N			
Maintenance Systems & Procedures	Y	1	6	6	Y	2	6	12	Y	3	6	18	N				N				N			
Dam Inspections	Y	1	6	6	Y	2	6	12	Y	3	6	18	N				N				N			
Personnel	Y	1	6	6	Y	2	6	12	Y	3	6	18	N				N				Y	2	5	10
Telephone, Telemetry	Y	1	6	6	Y	2	6	12	Y	3	6	18	N				N				Y	2	3	6
Control/Monitoring Systems	Y	1	3	6	Y	2	6	12	Y	3	6	18	N				N				Y	2	3	6
Control Building	Y	1	3	3	Y	2	3	6	Y	3	3	9	N				N				Y	2	2	4
Functions Services																								
Irrigation Water Supply	N				N				N				N				N				N			
Power Generation	N				N				N				N				N				N			

Time Period - Future (2080)	Climate and Other Variables and Events																							
Infrastructure Components	**Extreme Flood (PMF)**				**Safety Check Flood (10,000yr)**				**Design Flood (1,000 years)**				**5 Year Flood (550 m3/s)**				**Dead Storage Availability - Sediment**				**High Temperature**			
	8,000 m^3/s				**3,000 m^3/s**				**> 2,000 m^3/s**				**> Q_5**				**Sediment Load (11 MT/yr)**				**days with max temp > 29°C**			
	P Score =			5	**P Score =**			**6**	**P Score =**			**6**	**P Score =**			**6**	**P Score =3**				**P Score =2**			
	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
Drought Mitigation	N				N				N				N				N				N			
Flood Mitigation	Y	1	6	6	Y	2	4	8	Y	3	4	12	N				N				N			
Potable Water Supply - check location	N				N				N				N				Y	3	3	9	N			
Transportation Service	Y	1	6	6	Y	2	5	10	Y	3	5	15	N				N				N			
Fisheries	N				N				N				N				N				N			
Construction Period																								
Phase 1 < 5 years																								
Diversion Channel	N				N				N				Y	6	4	24	N				N			
Access Roads	N				N				N				Y	6	4	24	N				N			
Cofferdam	N				N				N				Y	6	7	42	N				N			
Phase 2 < 2 years																								
Spillway	N				N				N				Y	6	6	36	N				N			
Embankments	N				N				N				Y	6	5	30	N				N			
Phase 3 < 2 years																								
Irrigation Structures (intake)	N				N				N				Y	6	4	24	N				N			
Transportation																								
Supplies Delivery	Y	1	6	6	N				N				N				N				Y	2	3	6

ONE RIVER
ONE PEOPLE
ONE VISION

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