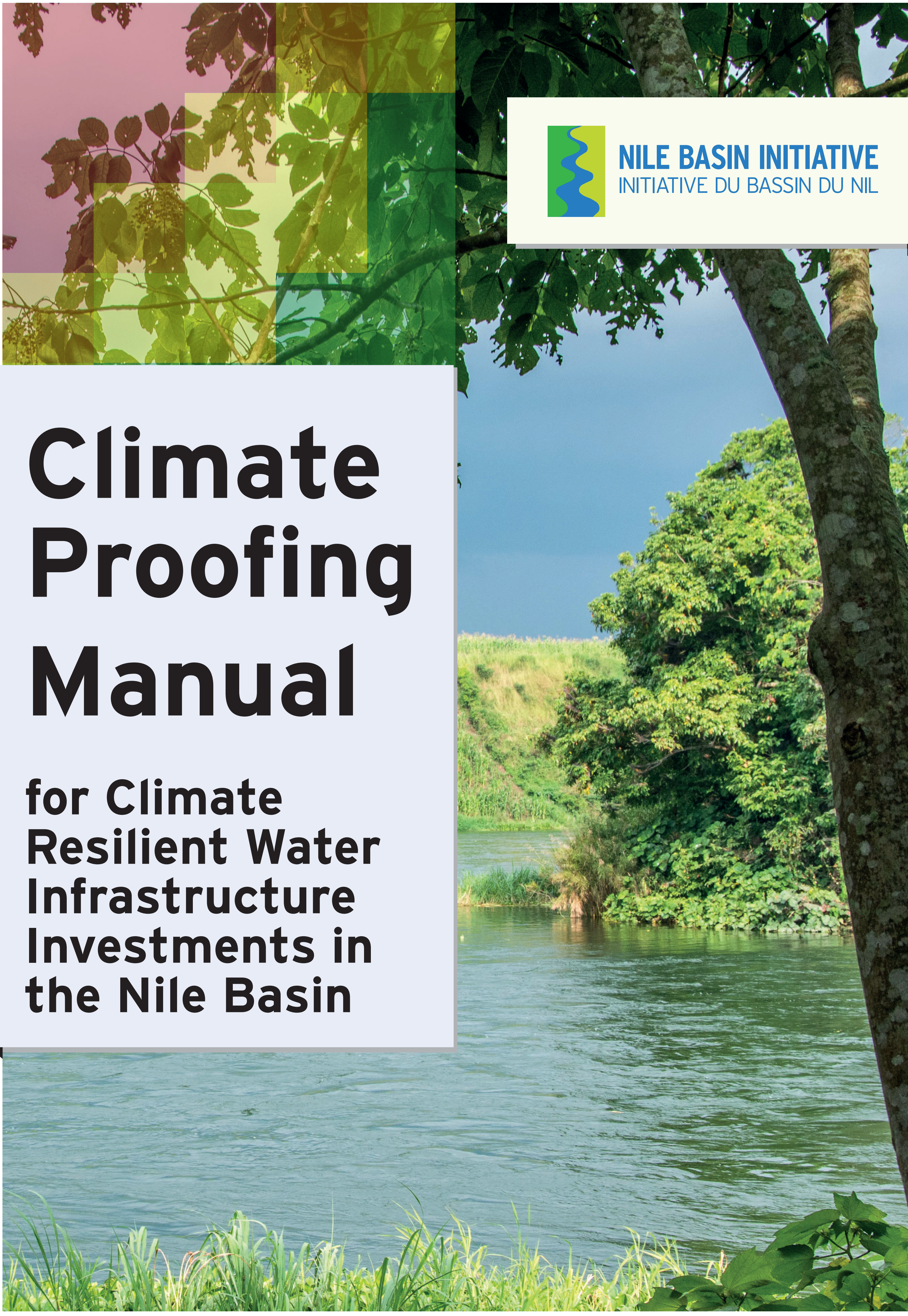

NILE BASIN INITIATIVE
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Climate Proofing Manual

for Climate Resilient Water Infrastructure Investments in the Nile Basin

DOCUMENT SHEET

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COLOUR CODES

Climate proofing – step by step instruction

- Step 1 » Scoping
- Step 2 » Risk Assessment
- Step 3 » Risk Treatment
- Step 4 » Monitoring & Evaluation (M&E)

Impact thresholds based on vulnerability considerations for type of assessment objective

- Insignificant
- Minor
- Moderate
- Major
- Extreme

Investment steps

- Sector policy, plans & regulation
- Project identification
- Project preparation
- Resource mobilization
- Construction
- Operation & maintenance retrofitting

PREFACE

Impacts of Climate change are increasingly affecting water security across the Nile Basin. There is increasing uncertainty in hydrological regimes with the associated water resources availability across the Nile Basin. Countries in the Basin, which already experience energy and water shortages, for irrigation agriculture, are extremely vulnerable to the effects of climate change. For these reasons amongst others, countries construct dams and reservoirs on the Nile to harness the water for socio-economic development. Climate change contribute to reduced flows, extreme flow variations or extreme high flows of Nile waters. The ability of water infrastructure to cope with such stress, to deliver its core services and to sustain its structural integrity becomes a challenge. This variability and inability to regulate, is a threat to crop production, energy security, as well as disaster resilience. Therefore, water governance is becoming an increasingly important pillar as guided by policy and best practice. Interventions at all levels are critical in addressing the climate change challenges, and unless quick actions are taken to arrest the situation, the impact will destabilise the social and economic development initiatives in the region. To achieve domestic and regional development objectives and to ensure water security and peace, and demand driven water management strategy ought to be instituted across the Nile Basin. Management of water infrastructure must take place in a holistic manner to ensure sustainability of investments in the basin.

Planning of related water infrastructure investments is informed by analysis of a range of historical and projected hydrological conditions with which a project must contend. Climate proofing is termed as the approach and defined as a process that ensures climate resilience throughout all stages of investment decision-making ranging from the climate proofing at policy and planning level and continues as investment projects through identification, preparation, construction, and operation.

The Nile Basin Initiative (NBI) has taken the effort together with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and implemented a workstream to pilot and test the concept of Climate Proofing. A number of investment projects under the Nile Equatorial Lakes Investment Program (NELIP) have been considered and a climate proofing manual developed. The core of climate proofing is to execute climate risk assessments. The methodological foundation of risk assessment piloted and tested under the NELIP is based on the provisions and principles of the Public Infrastructure Engineering Vulnerability Committee (PIEVC) hosted by the Climate Risk Institute (CRI), the Institute for Catastrophic Loss Reduction (ICLR) and GIZ. It has been customised to the requirements of water infrastructure in the Nile Basin region and the sequential steps of water investment procedures followed by NBI and its member states. Furthermore, through the contribution of ESSA ecosystem-based approaches to climate proofing, the so-called grey-green continuum had been brought up in the said manual.

The manual is strongly aligned within several complementary resources available at the NBI that in their sum represents the significant capacity offered to promote climate proofing and sow the seed for its institutionalization throughout the Nile Basin. The manual is programmed as a website under NBI's Integrated Knowledge Portal (IKP) and is aligned with more technical manuals and access to climate data banks on processing climate and hydrological data for the execution of risk assessment. Moreover, a climate proofing self-paced e-learning course is available for decision makers, planners, engineers, infrastructure owners, operators, and climatologists. For purposes of peer-exchange and expert networking, the NBI provides an entry point for access to an international expert community hosted by the Public Infrastructure Engineering Vulnerability Committee (PIEVC). Webinars, a marketplace for services on climate proofing is accessible to all interested experts throughout the Nile Basin.

Therefore, the manual and its complementary resources offers to NBI's member states as well as other stakeholders to engage in climate proofing. It promotes the notion that all investment decisions shall be based on sound climate proofing to ensure future water, food and energy security, in such a way that Environmental and Social Impact Assessments (ESIAs) takes care of environmental sustainability. This manual also provides food for thought of making climate proofing mandatory.

1 INTRODUCTION

1.1 The Manual's scope

This manual provides orientation for systematic climate proofing of infrastructure investments. Countries in the Nile Basin invest billions of dollars in durable water infrastructure such as dams, irrigation canals, wells, and others to provide services to people. Often, planners and policy makers do not take future climate change sufficiently into account when planning new infrastructure or rehabilitating an existing infrastructure project. This leads to high risks of insecure and volatile service provision and physical damage to costly investments, with potentially serious economic, political, and social consequences such as loss of livelihood and loss of lives. Building infrastructure today without considering future climate impacts is incorporating vulnerabilities that will later cause service disruptions and failures thus increasing costs to government, the private sector and users

The main objective of this manual is therefore to:

« provide guidance on a process that enables the integration of climate change in planning, designing and operating water infrastructure in the Nile Basin – in other words, to climate-proof new and existing infrastructure investment processes and projects.»

Overall, this manual provides an in-depth understanding of:

- Why climate proofing of infrastructure is essential and how water infrastructure is affected by climate change.
- What is climate risk, encompassing hazard, exposure and vulnerability.
- How the process of climate risk management evolves in the sequential successive steps of scoping, risk assessment and evaluation, risk treatment, and monitoring and evaluation.
- How this process of climate risk management is mainstreamed into NBI's ideal path of water infrastructure project cycle and decision making and therefore carried out at the different stages of infrastructure investment decision making, from policy and planning to project identification, preparation, construction and operation.
- How the role of Ecosystem-based Adaptation (EbA) is conceptualised and can be integrated into the resilience framing and climate risk management of grey infrastructure

Ecosystem Based Adaptation considerations

In climate-proofing water infrastructure, an important sub-objective is to consider, where possible, implementing Ecosystem-based Adaptation (EbA). The guideline will also explicitly provide guidance on how to integrate EbA into the climate proofing approach presented.

1.2 What is climate proofing – the path towards climate resilience

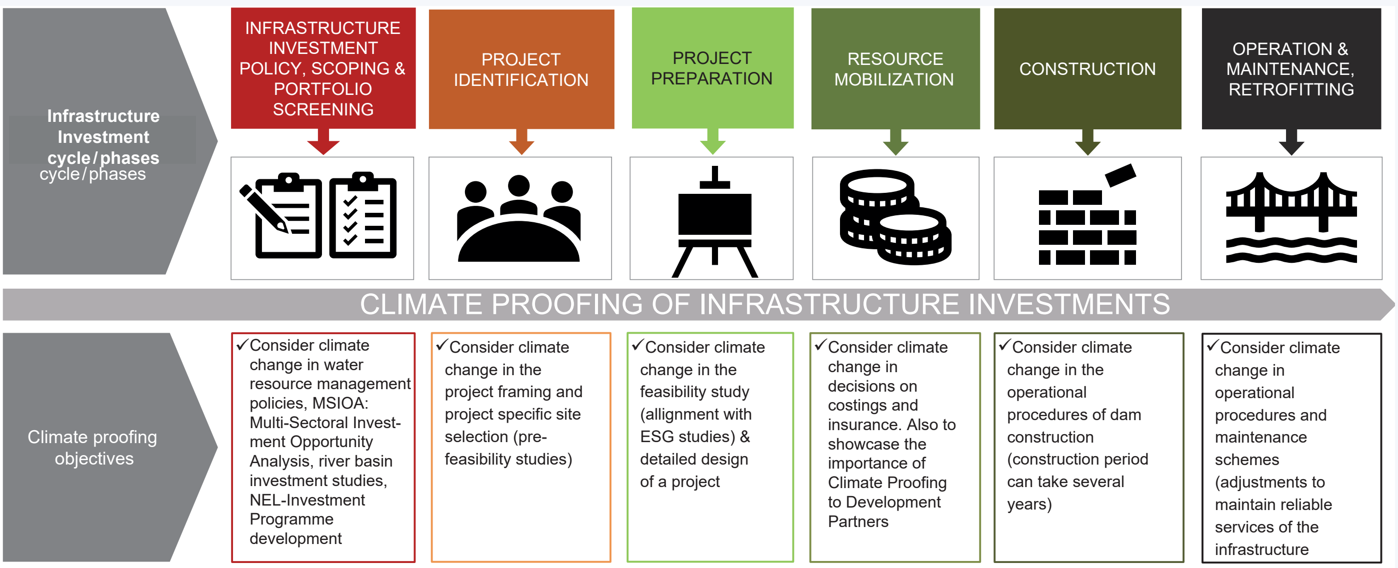
Climate proofing of infrastructure investments can be described as a process of assessing climate risks, developing, and implementing risk treatment solutions built-in-to pathways of infrastructure investment decisions. Climate proofing aims at establishing ecological, technical, economic, and social systems that can maintain and enhance the structural integrity and services of such infrastructures during the intended lifespan. For water related infrastructure this means addressing challenges related to:

- Changes in water supply (either increases, reductions and changes in timing of available water resources)
- Changes in water demand (for example crop water demand related to increased need for irrigation, changing settlement patterns, energy demand, environmental flows and minimum water requirements)
- Climatic changes that could affect structural integrity of infrastructure and safety of the society (for example floods that alter dam safety aspects)
- Changes that could affect operation (e.g., floods, sediments, design thresholds related to temperature, etc)

Through climate proofing, it is analysed how climate change may affect average future conditions (precipitation, air temperatures, hydrology) as well as future extremes (e.g., droughts and floods); and how these changes affect the challenges and opportunities posed to infrastructure investments. Hence, integrating the process of climate proofing into infrastructure investment decisions is crucial to avoid wrong investment decision that can occur due to uncertainty about the future, for example when a drier future is expected, when in fact, it turns out to be wetter. Moreover, climate proofing results in the identification of investment options that balance the risk of inaction with the risk of wrong action. One such preference is to avoid the worst outcome. In this case, the robust climate resilience strategy is to minimise, over all possible future climates, the maximum regret (where "regrets" are the damages—loss of revenue or missed opportunity to increase it—caused by not selecting the best response to any climate). Climate proofing will lead to cost increases when it entails investment in additional capacity or enhancements in water use efficiency; but it could also result in savings when facilities are downsized to avoid their underutilization in dry climates.

Climate Proofing aims at incorporating climate change throughout the entire project investment stream. This means incorporating climate risk considerations into every aspect of the policy and project development process and decisions by government, communities, and the private sector (Bockel, 2009; Amuzu et al., 2018). Hence, climate proofing starts with building-in climate resilience considerations already at the early stages of the project, similarly to social and environmental impact assessments. At each step of the project investment cycle, different adaptation alternatives must be evaluated, and preference must be given to alternative(s) with the lowest potential for regrets.

Figure 1 Conceptual approach towards climate proofing



1.3 Benefits of climate resilient water infrastructure

Climate resilient water infrastructure can ensure and maintain reliable service provision. For instance, it can help design enough storage capacity in reservoirs and adapting reservoir operation rules to deal with changing runoff patterns. This can help prevent water scarcity as water is used more efficiently. Climate resilient infrastructure also avoids lost revenues from underperforming hydropower or irrigation infrastructure in drier climate futures. It also avoids the opportunity cost of not taking advantage of an abundance of exploitable water resources in wetter climate futures. In wet climate futures, hydroelectric facilities generate larger amounts of electric power without any additional investment which in turn allows hydro to replace fossil fuel–based energy generation and reduces overall prices (Groves et al., 2015). Knowing in advance that a wet future will materialise, it makes sense to expand generation capacity to produce more hydropower; in a dry future, it is preferable to reduce generation capacity to avoid sinking capital in equipment that will end up being underutilised.

Thereby, **climate proofing can also foster and sustain the success of transboundary cooperation, as well as benefit sharing mechanisms of a river basin**. The idea of benefit-sharing in the management and development of water resources in a transboundary basin may allow for optimization of resource use and increase overall benefits[1]. Particularly, when it comes to shifting from a necessarily competitive zero-sum game (where one country's water allocations come at the expense of the other's) into an at least partly cooperative positive-sum game[2]. Here, climate change can threaten such a cooperative positive-sum game. Though, climate proofing can lead to the use of technological adaptations that uses water more efficiently, hence minimizing the use of water such as for irrigation, designing enough storage capacity in reservoirs and adapting reservoir operation rules to deal with changing runoff patterns. Hence, climate proofing plays an important role for avoiding or delaying the generation of conflict over water and allows benefits to be better shared equitably among states.

1 For instance, water might be used more efficiently for food production in certain parts of the basin than in others or coordinated dam operation across a basin can increase overall efficiency in hydropower generation. Moreover, one country's resource use for a certain purpose can create benefits for other riparian countries. One example for such win-win constellations would be that the construction of dams for hydropower production can simultaneously result in improved potential for downstream flood management, improved downstream navigation, greater downstream hydropower potential due to more stable flows (Kramer and Pohl, 2016)

2 For example, where one country's water uses and management produces co-benefits for other riparian countries, or the optimization of water across the basin creates a 'benefit surplus' that can be shared among riparian's.

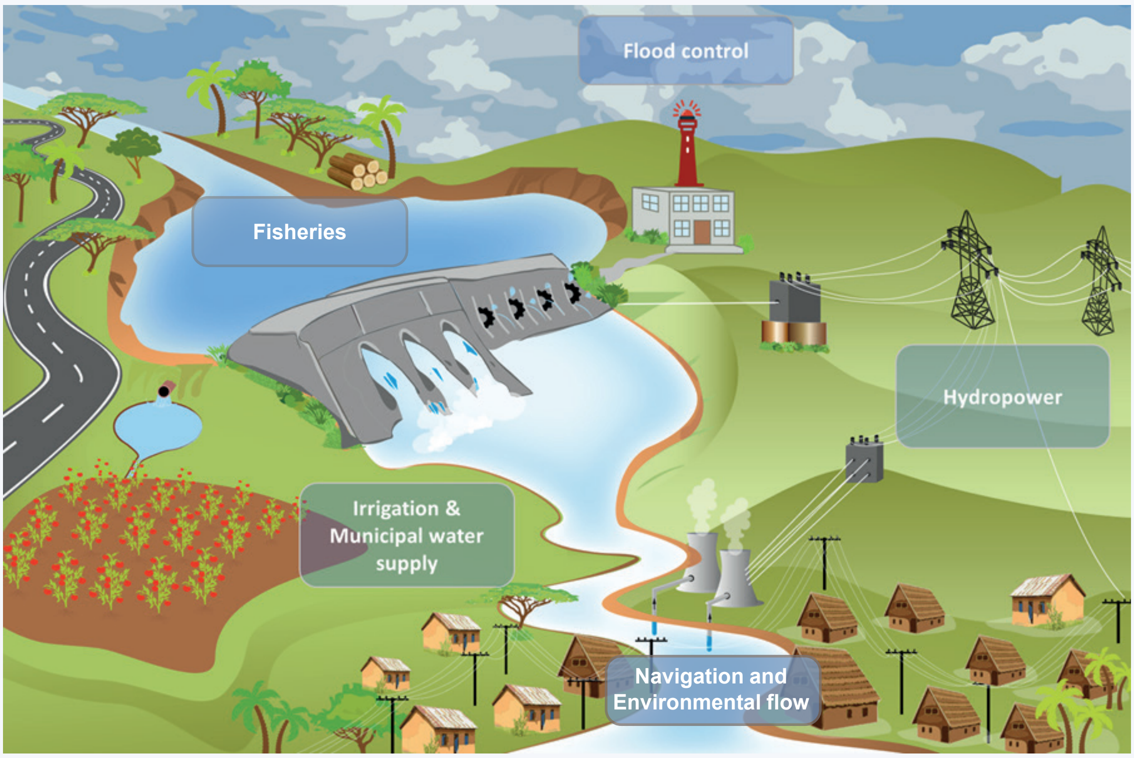
Ecosystem Based Adaptation considerations

Many strategies are available to climate-proof water infrastructure so that it is less susceptible to climate hazards. Some of these strategies exist along a “green-to-grey” continuum. That is, to varying degrees, they harness the benefits of biodiversity and ecosystem services to reduce climate change related impacts to water infrastructure and related services. These strategies are referred to as nature-based solutions for climate change adaptation, or simply ecosystem-based adaptation.

1.4 The type of infrastructure in focus of this manual

From the river basin scale all the way down to the household scale in the Nile Basin, many different types of infrastructure are required to provide the water-related services upon which economic sectors, communities, and people rely. Examples include dams, irrigation canals, wells, pumps and pump stations, cisterns, mine tailings ponds, water treatment plants, sewage treatment plants, culverts, embankments, water pipes, hydropower generating facilities, and more. These assets provide critical services like domestic water supply, irrigation for crops, hydropower production, water quality treatment, navigable waterways, flood and erosion management, as well as recreation opportunities.

Figure 2 Illustration of a standard multipurpose project including facilities for irrigation, M&I, flood control and hydropower



Though the Nile Basin currently remains the only region of Africa without a functional regional power grid, and very little power is traded among countries, all Nile riparian countries have ambitious national hydropower infrastructure development plans, to fuel economic growth and support poverty alleviation. Similarly, agricultural productivity targets across Nile riparian countries will require huge investments in irrigation infrastructure. These systems will fundamentally rely on water supplied by the Nile River and its tributaries. Already, agriculture is the biggest user of water in the Nile River Basin (NBI 2021).

1.5 Target group of the manual

The manual is intended primarily for owners, designers, Dam Safety Specialists, developers, and operators of water infrastructure (public and private). Others who might use the guide include professionals hired to work on these projects, financial institutions, and governments. The guide ***should be used by project teams*** that include ***representation from across the following types of participants***. The roles are explored in the following according to types of stakeholders:

- **Policymakers from government agencies** responsible for planning and regulating water infrastructure and energy systems.
- **Governmental and institutional bodies** have a key role to play in the consistency and efficiency of climate resilience strategies and actions across socioeconomic sectors and geographic regions within their jurisdiction. Establishing contact and engaging with governmental and institutional bodies may facilitate the collection of data and studies which form the basis for screening the potential climate risks of projects.
- **Policy makers, agencies and regulators** that have statutory responsibility in the energy or water resources sectors must deliver advice and a legal framework that considers the risks associated with climate change.
- **Supranational institutions** from the energy or water sectors, river basin management organisations (such as NBI), national and local governments, investors, non-governmental organisations (NGOs), local or regional water resources agencies, meteorological and hydrological services and scientific institutes can also contribute to the resilience of a water resources project by setting regulations, delivering institutional capacity building and training, creating dialogue platforms and producing and sharing knowledge that can foster the knowledge and experience of climate resilience.
- **Financial institutions** who may request a climate risk assessment as a requirement for financing.

- **Project owners and managers**
  - These are project owners, developers, and operators responsible for planning, development, design, construction, and operation of the projects to consider climate risks in new and existing multi-purpose projects. Climate proofing for a water infrastructure project requires resources and actions. Therefore, those involved in managing the project should ensure climate resilience is appropriately assessed and should provide the necessary resources to undertake the preparation and implementation of a climate resilience strategy.
  - Responsibilities must be assigned to experienced or trained specialists. For major projects, climate resilience teams/experts must be fully coordinated with the engineering and ESIA teams. Climate Risk Assessment may be considered an integral part of the overall development of assessment of a project.
- **Technical officers**
  - These include climate change practitioners and project engineering and ESIA teams. They are expected to:
    - Use the approaches defined in the guideline to assess climate change risks
    - Identify climate resilience/proofing measures
    - Report the results to the decision makers and stakeholders.

  They should share the findings from their respective early assessments when undertaking a climate risk assessment or securing senior-level support for the process through information on key business risks, to ensure that support is gained in terms of resourcing and budgets.

1.6 NBI's mandate and policy framework for climate proofing

1.6.1 NBI's core functions

The Nile Basin is one of the most critical trans-boundary hydrological basins in Africa with the River Nile playing a crucial role and resource for most of the economic and social activities for the countries in Eastern and North-Eastern Africa. For the management of its common resources, the Nile Basin Initiative (NBI) as an all-inclusive basin-wide institution was established in 1999. It is an intergovernmental partnership of 10 Nile Basin countries, namely: Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, South Sudan, The Sudan, Tanzania and Uganda. Eritrea participates as an observer.

The objectives of the NBI are to

- Develop the Nile Basin water resources in a sustainable and equitable way to ensure prosperity, security, and peace for all its people.
- Ensure efficient water management and the optimal use of the resources.
- Ensure cooperation and joint action between the riparian countries, seeking win-win gains.
- Target poverty eradication and promote economic integration.
- Ensure that the program results in a move from planning to action.

The NBI institutional framework consists of three key institutions

- The Nile Council of Ministers (Nile-COM), which is comprised of Ministers in charge of Water Affairs in each NBI Member State, provides policy guidance and makes decisions. The council holds regular annual meetings as well as extraordinary meetings.
- The NBI Technical Advisory Committee (TAC) is made up of senior civil servants and provides technical advice and assistance to the Council of Ministers. The committee is made up of one representative from each riparian country and one alternate. It meets two to three times a year.
- The NBI Secretariat (Nile-SEC) provides administrative support to the Council of Ministers and the Technical Advisory Committee. The Nile-SEC is responsible for the overall corporate direction. It is based in Entebbe, Uganda and is headed by an Executive Director.
- Two Subsidiary Action Programs (SAPs) are managed by the Eastern Nile Technical Regional Office (ENTRO), which is based in Addis Ababa, Ethiopia, and the Nile Equatorial Lakes Subsidiary Action Program Coordination Unit (NELSAP-CU), which is based in Kigali, Rwanda. In addition, various projects have regional project management units located in different countries of the Nile Basin.

1.6.2 NBI's programmes, frameworks and strategies

Climate change affects the whole region of the Nile Basin. Due to its transborder character, the challenges of climate change and water supply are best addressed by the Nile Basin Initiative (NBI). Being the only forum that brings together the Nile riparian states, NBO is mandated to initiate and implement measures that complement national efforts to address transboundary challenges including climate change.

Strategy, policy and planning mechanisms that affect infrastructure investments in the Nile Basin include:

- **The "Shared Vision Program" (SVP)** was designed to build trust and capacity, as well as an enabling environment for investments as well as ensuring consideration of transboundary considerations in national policies. While the Subsidiary Action Programs (SAPs), such as the Nile Equatorial Lakes Subsidiary Action Program (NELSAP), or the Eastern Nile Technical Action Program (ENSAP) were designed to support identification, negotiation, and implementation of cooperative investment projects, with a focus on mutual and sustainable benefits for the countries involved.

- **The Nile Basin Sustainability Framework (NBSF)** comprises a suite of policies, strategies, and guidance documents. It functions as a guide to national policy and planning process development and seeks to build consensus. The NBSF is intended to contribute to the gradual alignment of the Basin's body of (national) water policies to meet international good practice, and to help demonstrate to national governments and international financiers of water infrastructure that the NBI has a systematic approach for dealing with issues of sustainable development within the Basin. Without the NBSF, there would be no consistent guidance for the sustainable development of new investments and no coherent guidance for the achievement of cooperation in sustainable water management and development. Addressing climate change is one of the sustainability pillars within the Nile Basin Sustainability Framework (NBSF).

- **The NBI Strategy** translates the shared vision objective "to achieve sustainable socio-economic development through equitable utilization of, and benefit from the shared Nile Basin water resources" into basin development goals that NBI will work towards; and further expounds on what contributions NBI will make over the ten-year period. The 10 Year Strategy will be implemented through 5 Year Programs prepared by the three NBI Centers and will be funded by the Nile Riparian countries with support from Development Partners. The strategy defines the following six strategic goals and priorities:
1) Water Security,
2) Energy Security,
3) Food security,
4) Environment Sustainability,
5) Climate Change Adaptation, and
6) Strengthen Trans-boundary Water Governance.

- **The NBI Climate Strategy.** The overall goal of The NBI Climate Change Strategy which was published in June 2013 is to strengthen basin-wide resilience to climate change and ensure climate compatible water resource management and development. The NBI Climate Change Strategy sets out the NBI's approach for a joint transboundary river basin level response to support climate compatible water resource development in the Nile basin (NBI, 2013).

The development of the climate proofing guideline can be considered a specific component of outcome 3 of the Climate Change Strategy which is aimed at ensuring that climate change is embedded in relevant NBI strategies and programs, and capacities are enhanced to address climate risks at transboundary and national levels:

Outcome 3 of the Climate Change Strategy:

"Relevant NBI policies, strategies and guidelines will consider the key climate risks, impacts and vulnerabilities facing the Nile Basin and ensure that the strategic objectives, outcomes and actions contained in policies, strategies and guidelines reflect the challenges posed by climate change. NBI will strengthen its own as well as national capacities to consider the transboundary environmental and social implications of their climate change and water resource management and development responses."

The climate proofing guideline will contribute to the realisation of the following five strategic objectives that govern NBI's Climate Change Strategy:

- **Objective 1**: Strengthen the knowledge base to enhance common understanding of climate change risks and its impacts on water resources, ecosystems, and the socio-economic system of the Nile Basin

- **Objective 2**: Strengthen the long-term capacities for addressing climate risks and uncertainty in the Nile Basin at national and transboundary levels

- **Objective 3:** Support climate resilient planning and implementation addressing climate risks and uncertainty in NBI's programs.

- **Objective 4:** Promote scalable low carbon development through enhanced transboundary cooperation in areas such as protection of wetlands as well as clean energy use and development

- **Objective 5:** Strengthen basin-wide climate finance access and the capacity for development of feasible projects in the Nile Basin

1.6.3 United Nations Sustainable Development Goals

In 2015 the United Nations Summit on Sustainable Development in New York established the global agenda for sustainable development until 2030 and defined a list of 17 objectives, i.e., the Sustainable Development Goals (SDGs) on which to focus commitments for the next fifteen years. The 17 SDGs (Figure 3) replace, and broaden, the Millennium Development Goals (MDGs) expiring in 2015 (UN, 2015; Ferranti, 2019).

Figure 3 United Nations' Sustainable Development Goals (SDGs)[3]

3 Image adapted from https://sustainabledevelopment.un.org/sdgs and https://www.merckgroup.com/en/cr-report/2018/pics/files/sdg_en.svg

Sustainable management of water resources and, by extension, development of climate-proof water infrastructure is central to the achievement of all 17 SDGs. Most directly related to climate-proofing infrastructure is

- **SDG 9** – Industry, Innovation, and Infrastructure, which includes a clause to "build resilient infrastructure" that is "environmentally sound", and

- **SDG 13** – Climate Action, or "taking urgent action to combat climate change and its impacts"

- **SDGs 1 & 2 –** The services provided by water infrastructure underpin many other SDGs such as 1 – End Poverty, 2 – End Hunger, both of which require domestic and agricultural water security that can be enhanced by infrastructure like irrigation canals, dams, and reservoirs.

- **SDGs 6, 7, 8 and 10** are closely related to SDG 1: Clean Water and Sanitation, Affordable and Clean Energy, Decent Work and Economic Growth, and Reduced Inequalities.

- **SDGs 16 and 17** – The joint development of water infrastructure in shared river basins has long promoted cooperation between nations, which contributes to SDGs 16 and 17 – Partnerships for the Goals, and Peace, Justice and Strong Institutions

Ecosystem Based Adaptation

For each of these SDGs, ecosystem services like water quality regulation, hydropower production, and water's role as an input to production of goods and services, as well as equitable access to those things, are essential. Ensuring the reliable supply of these ecosystem services well into the future requires building climate-proof water infrastructure using recommendations such as those presented in this Guideline. Water infrastructure is a key part of making communities inclusive, safe and capable of recovering from climate-related hazards (SDG 11 – Sustainable Cities & Commodities) (e.g., water supply during emergencies). Used appropriately, water infrastructure can also be an ally in the protection and restoration of terrestrial ecosystems like freshwater rivers, lakes, forests, and desertificated areas (SDG 15 – Life on Land). This latter role for water infrastructure is particularly enhanced when ecosystem-based adaptation (EbA) is applied as part of an overall climate proofing strategy

2. CLIMATE RISK AND ENTRY POINTS FOR RISK TREATMENT

2.1 Climate change impacts on water infrastructure

As climate change will likely result in changes to the timing, frequency, intensity, and/or duration of a range of conditions like severe storms, floods, droughts, sea level rise, and storm surge impacts on water infrastructure are anticipated that directly damage water infrastructure, affect operating and maintenance needs, impacting dam safety, negatively impact service levels, and/or reduce the service life of assets. For example, in dry climates, less hydropower than planned is produced, and the difference needs to be balanced by more expensive power sources, such as diesel generators. Or, irrigation underperforms compared with the no-climate-change scenario, and countries will need to make up for the deficit in food production. The risk of damage to the built assets (dam, powerhouse, substations, transmission lines, etc) can be increased by climate change due to several causes. Examples are:

- Carbonation-induced corrosion damage (due to increases in atmospheric CO_2)
- Increase in chloride-induced corrosion of concrete due to temperature and Humidity increases
- High temperatures affecting cooling of substations and transformers and the operation of some components
- Increases in the flood amounts for a given return period
- Increased frequency of landslides causing bank erosion and increasing sediment load, altered upstream land use/forest practices that change sediment load and capacity for storm water retention, loss of wetlands due to drought

The Fifth Intergovernmental Panel on Climate Change (IPCC) assessment report (Climate Change, 2014) introduced a concept for understanding risk of impacts from climate change. Accordingly, the IPCC defines risk as the potential for impacts where something of value, such as water infrastructure, is at stake. In the context of water infrastructure climate risk can be defined as:

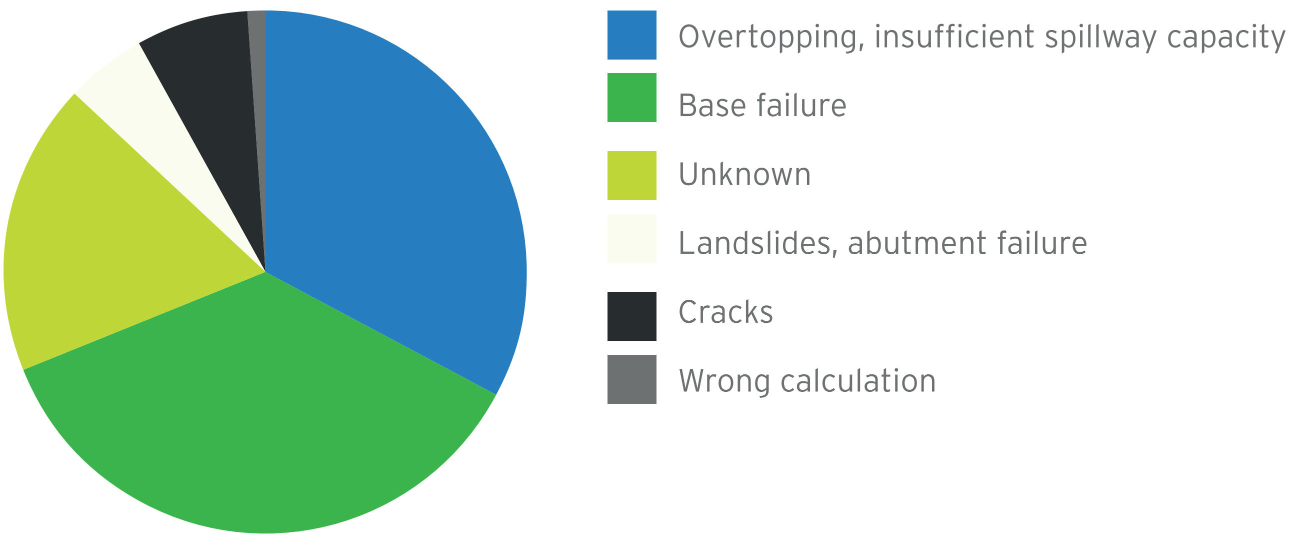
> "The probability of experienced or future reduction and loss of service reliability, loss and damage to the structural integrity, as well as loss of human lives and their assets in the context of climate change".

Box 1 Main causes of dam failure rooted in patterns of vulnerability

The failure of dams as a consequence of climate change can have extreme consequences depending on the size, location and type of the dam. Dam failures can be associated with the following topics:

- First impoundment: 38 per cent of all dam failures occurred during the initial filling of a reservoir
- Main reasons of dam failure for concrete dams are internal erosion of foundation and lack of resistance to sliding
- Main reasons for dam failure of earthen dams are piping and base failure
- The cause of failure related to spillways is due to insufficient spillway capacity (22 per cent)
- Dam failure mostly happen as a series of incidences creating a failure path. Two examples of failure paths:
  - Debris blocks part of the spillway → water level rise beyond dam crest → overtopping of the dam → erosion of the downstream dam side → dam failure
  - Earthquake → landslide into the reservoir → overtopping of the dam → erosion of the downstream dam side → failure

Figure 4 Overview of reasons for dam failure



The description of impacts can relate to the following five (5) impact dimensions:

Project feasibility

- Climate changes can impact the revenue streams of investments.
- The worst-case scenario for production is when there is a reduction in inflow.
- Flood risk can also be a problem with increasing runoff.
- Increases in run-off can be good if there is capacity in the system to exploit them.
- Changes in the timing or in flow-duration curves (regardless of changes in the average amount of water) can require modifications to operation strategies. e.g., for reservoirs to deal with the changes in energy generation and new environmental threats.
- The uncertainty caused by potential climate change can affect the perceptions of risk by investors thus increasing the cost of financing. This may lead to electricity and water supply constraints.
- In areas with significant increase in precipitation and therefore run-off, the risk of flooding will increase, and the safety of dams may require re-examination to cater for the changing flood characteristics.

Flood and sediment transport characteristics

- In areas with significant increases in precipitation and therefore run-off, the risk of flooding will increase, and the safety of dams may require re-examination to cater for the changing flood characteristics.
- The increase in flood values is a threat to structures that are dimensioned for lower floods.
- An assessment of the impact of changed floods is useful to determine the extent of modifications necessary to protect existing and future infrastructure.
- Sediment yield and transport characteristics may also be affected in areas that are prone to erosion.
- Reservoir storage capacity can be reduced by increasing sediment yield and the number of operations for removal of sediments may need to be increased and the technology for sediment removal may require adaption to meet the new challenges.

Socio-economic and environmental outcomes

- Minimum environmental flows that can no longer be sustained or that are sustained at a high cost to electricity generation, water supply and the environment
- Increased flood flows that affect downstream or upstream settlements and infrastructure
- Changing Land cover that may influence the rainfall-runoff relationships of catchments
- Conflict with competing water uses

Operations

- Sediment yield and transport characteristics may also be affected in areas that are prone to erosion.
- Through changes in flood and sediment transport characteristics reservoir storage capacity can be reduced by increasing sediment yield and the number of operations for removal of sediments may need to be increased and the technology for sediment removal may require adaption to meet the new challenges.

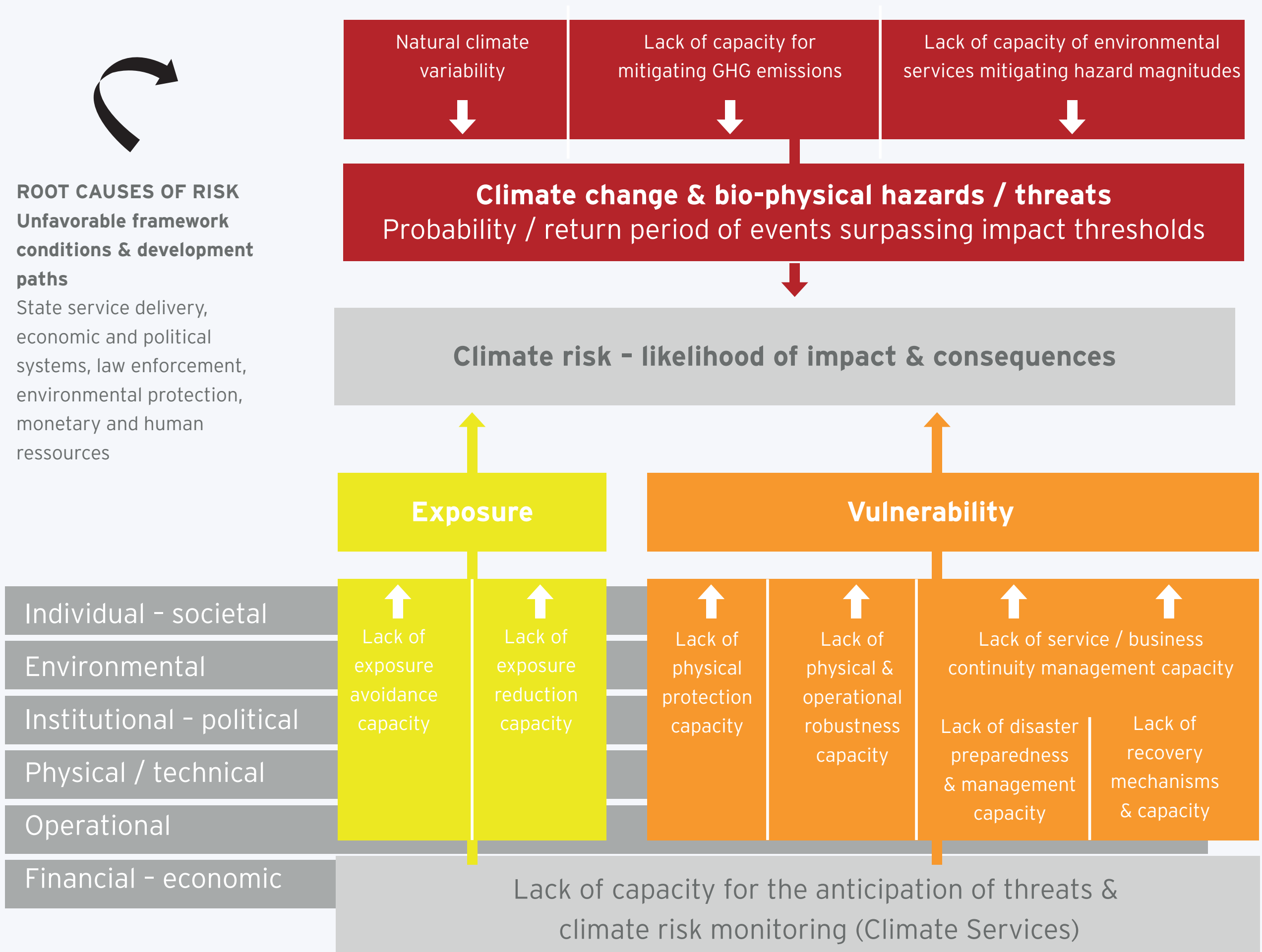
2.2 What causes climate impact - The contributing role of hazards, exposure and vulnerability

Based on the IPCC (2022), the risk of climate-related impacts on water infrastructure is rooted in several dimensions explored in this chapter, including

- evolving **climate-related hazards** (including hazardous events and trends),
- the **exposure of water infrastructure to these climate related hazards**, as well as
- the **vulnerability of exposed water infrastructure to suffer loss and damage**

For infrastructure systems the causal structure of risk of loss & damage can be analysed based on the following risk causality-framework (Compare Figure 5 and following text). For identifying adaptation options understanding the causal structure of risk and their root causes is essential.

Figure 5 Causality of climate risk – Framework for climate risk of infrastructure (Adapted from Baumert, 2016)



Risk of loss & damage of infrastructure systems are attributed to:

1. **Climate change, and its impacts on the bio-physical environment as a driver of risk** on which infrastructures depend on. 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 & damage. The term hazard usually refers to climate-related physical events or trends or their physical impacts. Extreme events can also be triggered by the lack of capacity of environmental services mitigating hazard magnitudes (e.g., up-stream deforestation increasing risk of extreme flood events posed by climate change).

2. **Exposure as a driver of risk.** Exposure is defined as the presence of infrastructures and its components, people, livelihoods, species or ecosystems, environmental functions, services, and resources, or economic, social, or cultural assets in places and settings that **could** be affected by climate related hazards.

- The lack of exposure avoidance: anticipatory risk zoning for new investments (prohibit construction, or conditional construction), and

- The lack of exposure reduction through adequately governing retreat in cases where increasing resilience on the spot is no option anymore, or neglection of analysis revealing that the type of investment is economically not viable under climate change conditions.

3. **Vulnerability as a driver of risk.** 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 (IPCC Glossary, 2014, p.128). Often vulnerability is also viewed as the result of "unmanaged risk". Therefore, vulnerability can be considered as being rooted sensitivity conditions as systems lack capacity for **reducing the sensitivity** and **increasing the adaptive capacity** of the infrastructure system. A more detailed definition of entry points for understanding drivers of vulnerability are:

- The lack of capacity for **anticipating current and future risks and vulnerabilities** in pursuit of reducing exposure, sensitivity and increasing adaptive capacity of the water infrastructure.

- The lack of the infrastructure systems to be adequately **protected** to specified climate events (e.g., degraded upstream ecosystems acting as flood buffers, inadequate spillway design, inexistence of bypassing channels, cooling of energy systems against heat stress, protection gear for staff, inadequate protection from natural hazards (e.g., landslides, erosion into the reservoir)

- The lack of water infrastructure systems to be adequately **physically and operationally robust** to specified climate events regarding its physical structure and functionality (sediment operations, inadequate dam materials, internal erosion of foundation, lack of resistance to sliding, piping and base failure, uncontrolled seepage, inappropriate initial filling of the storage dams)

- The lack of systems to perform adequate **business continuity management to specified climate events, including**:

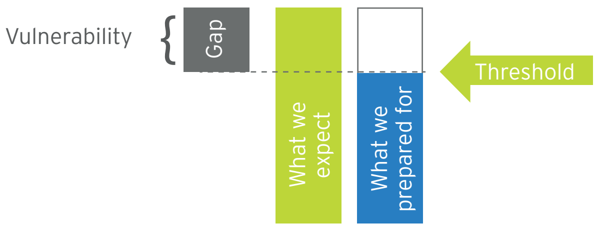
  - The lack of performing disaster management (Preparedness, early warning systems and response, relief contingencies and operations)

- The lack of provision or existing redundant systems to maintain function in times of crises

- The lack of recovery & reconstruction contingencies and operations in the course and aftermath of climate related physical extreme events

In Engineering vulnerability concepts, vulnerability can be conceptualised through "impact thresholds". A vulnerability exists when the asset can reasonably experience loads in excess of its capacity, depending on the degree of robustness, protectiveness and capacity to provide residual risk management. In vulnerability assessment, the point where climate load exceeds capacity is called the *threshold value*.

Box 2 Impact thresholds as an indicator of vulnerability to a specific stressor



Climate change impacts on infrastructure are associated with the exceedance of different threshold values. An impact threshold defines critical climate conditions at which a system of interest in sensitive to and hence damages and losses are likely to occur. Hence, its definition and calculated value is based on the system of interest's characteristics to experience harm. The definition of impact thresholds is key for climate risk assessment and requires the inclusion of end-users for developing climate service products.

Thresholds can include

- Project Goals such as expected demand, supply of the services being provided.
- Technical thresholds for safety of structures such as Design floods, design loads and design temperatures.
- Financial thresholds such as Net present value (NPV) or Internal rate of return (EIRR)
- Social and environmental indicators such as minimum downstream flow requirements

Example - Design Flood as a performance metric

An example of a performance metric is the design flood for a project. A dam may for example be designed for a T=1000-year flood (Q1000) based on its consequence class (i.e., Qdim =QT). The consequence class is usually based on safety considerations in case of a dam break. This is usually decided based on analysis of historical flood data, reservoir size, dam break analysis, potential damages, and loss of life in case of a dam break.

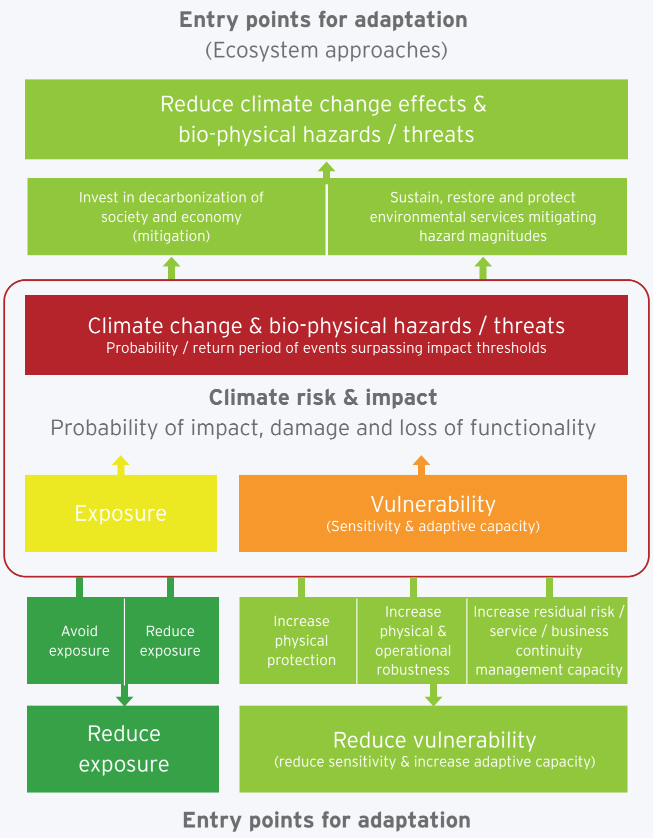
Next to the need to identify threshold values as an indicator of vulnerability understanding drivers of the way thresholds are being configured is important. Especially with existing infrastructure that had been build it is necessary to understanding more in-depth the root causes of risk, often embedded in unfavorable societal, political, regulative, economic, and environmental framework conditions and contexts in which infrastructures investments are carried out or infrastructure systems are operating.

» For more detailed climate hazard specific impacts and adaptation measures please visit long list Annex 5.5.

2.3 Entry points for risk treatment

- Risk treatment is specifically needed in areas where the risk assessment identified the greatest weaknesses. The following image sets out the major entry points for possible risk treatment interventions. Overall, reducing risks can be achieved via reducing vulnerabilities or reducing exposure to climate hazards, to pool or share risks where they exist, and to manage residual risks and uncertainties such as via emergency preparedness or increasing capacity to cope with disruptions.

Figure 6 Climate risk and entry points for defining risk management options



Hazard magnitude reduction:

- Investments into low carbon development
- Ecosystem service rehabilitation and Ecosystem based adaptation to new climate conditions

Exposure reduction:

- Restrict or avoid infrastructure systems located at hazardous locations
- Reduce existing exposure through abandon infrastructures in the high-risk areas

Vulnerability reduction:

- Investments into **protection** of infrastructure beyond identified and agreed thresholds.
- Investments into the **physical and operational robustness** of infrastructure assets and their single components.
- Investments into **residual risk management**, such as preparedness, early warning and response systems, preparedness and business continuity management that can entail creating redundant critical systems, relief and recovery mechanisms.

» For more detailed climate hazard specific impacts and adaptation measures please visit long list Annex 5.5.

2.4 In the spotlight – Ecosystem based Adaptation for resilient water infrastructure

Many strategies are available to climate-proof water infrastructure so that it is less susceptible to climate hazards. Some of these strategies exist along a "green-to-grey" continuum. That is, to varying degrees, they harness the benefits of biodiversity and ecosystem services to reduce climate-related impacts to water infrastructure. These strategies are referred to as nature-based solutions for climate change adaptation, or simply ecosystem-based adaptation (EbA).

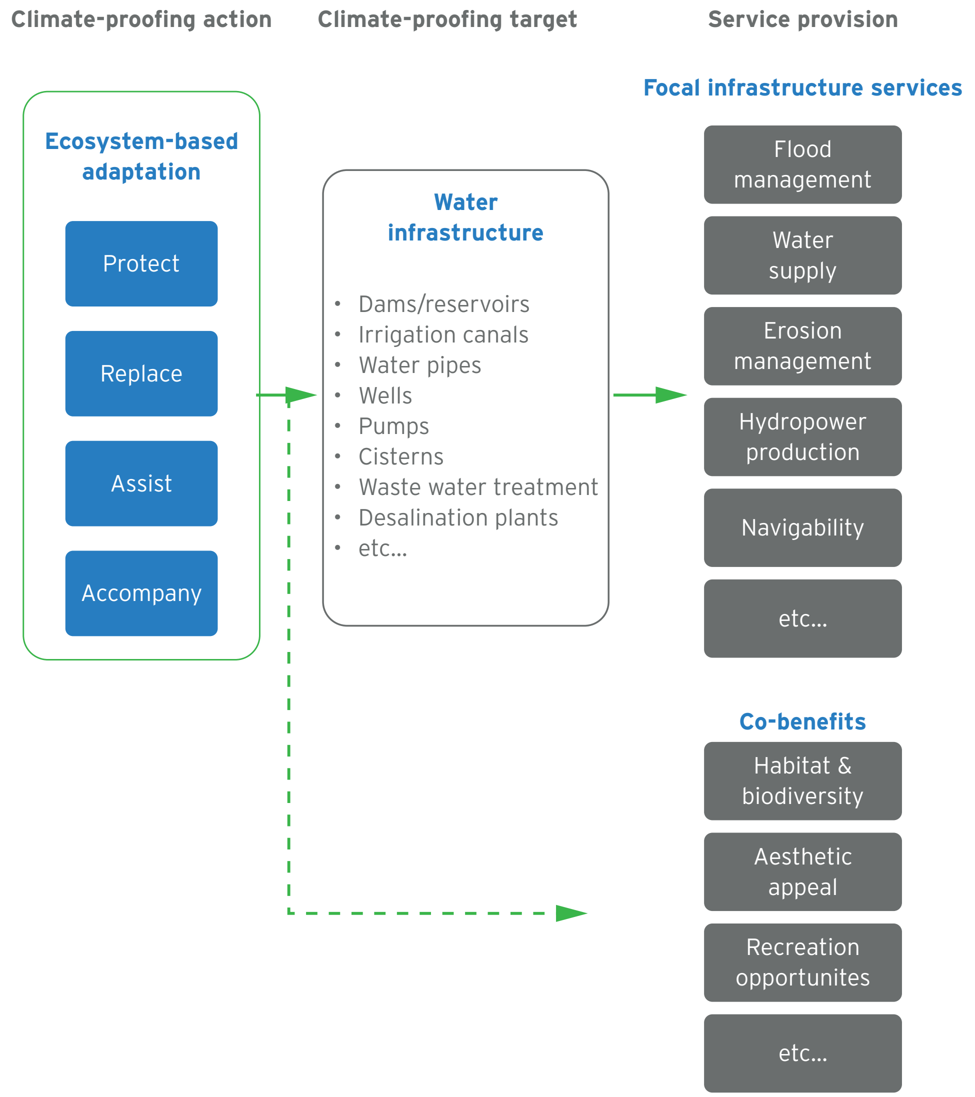
Ecosystem-based adaptation is "The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change" (Convention on Biological Diversity, 2009). EbA can also be less costly to maintain over long time horizons because it relies on the self-regulating characteristics of nature (ADB 2019).

In the context of water infrastructure, EbA refers to ecosystem services that either protect, support, replace, or supplement hard/grey water infrastructure, thereby extending its lifespan and reducing operation and maintenance needs, while simultaneously providing co-benefits like habitat provision and recreation opportunities. In cost-benefit analyses, EbA alternatives can outperform hard/grey solutions particularly when co-benefits are considered. The interactive conceptual diagram illustrates how ecosystem-based adaptation (EbA) can be harnessed as climate-proofing actions targeting water infrastructure to support more resilient provision of focal services and co-benefits.

In the Nile Basin, the most relevant EbA options for climate-proofing water infrastructure are those that minimise the impacts of increased sedimentation due to erosion, flood damages, low flow conditions, evaporation, and concentration of pollutants since these stressors pose the greatest risk to water infrastructure and the services they provide. Example EbA alternatives that can assist in managing these impacts include re-meandering of rivers, creation or restoration of side-channels, flood plain widening, installation of green embankments, riparian planting, and forest restoration, altered land use practices, wetland restoration, and the creation of bioswales for urban drainage (sources).

Figure 7 is a conceptual diagram showing how different types of EbA (Protecting, Replacing, Assisting, Accompanying) can be applied to generate ecosystem services resulting in more resilient water infrastructure that, in turn, reinforces the reliability of focal service provision by that same infrastructure (positive feedback).

Figure 7 A conceptual diagram on the role of EbA for climate resilient infrastructure



As Figure 7 illustrates, several ecosystem-based adaptation actions can be applied (options 1-4), each of which supply different ecosystem services. These actions can be organised into different types (colored ovals) based on how they interact with hard/grey infrastructure projects:

- Protecting options supply ecosystem services that directly protect a hard/grey infrastructure project from climate hazards, increasing its lifespan and reducing operating/maintenance costs, while also providing co-benefits.

- Replacing options supply ecosystem services that completely replace the need for a hard/grey infrastructure project and are more resilient to climate hazards, while also providing co-benefits.

- Assisting options supply ecosystem services that complement a hard/grey infrastructure project by increasing focal service provision beyond what could be provided by the project alone, thereby improving capacity to continue service provision when impacted by climate hazards, while also providing co-benefits.

- Accompanying options provide no services that directly or indirectly improve the adaptive capacity of a hard/grey infrastructure project or its focal services but can be implemented as part of the project to provide co-benefits that increase overall adaptive capacity of society to climate hazards.

EbA might not be an optimal solution in all cases and different criteria should be used to identify and prioritise the best climate proofing options. For example, if the only management objective is to protect water infrastructure against a 10,000-year flood, many EbA alternatives would not be viable because they would have a negligible effect against such an extreme event. Decision criteria such as feasibility, relevance, costs, benefits, and many others can be applied and EbA's contribution to cumulative benefits should be considered (World Bank 2017, ADB 2019). Cost-benefit analyses (CBA) is a particularly useful decision-support tool that is often applied to help understand the net benefits to society of different management alternatives. Doing cost-benefit analysis for EbA options can be quite different from doing the same for hard/grey infrastructure alternatives because some ecosystem services provided by EbA options are not bought and sold in markets (especially co-benefits like habitat and recreation opportunities) (NOAA 2015). This "non-market value" to society requires special economic valuation techniques to assign monetary values to non-market goods and services so the net benefits of a project can be compared on a common scale. To learn more about how to implement cost-benefit analysis for EbA, please refer to the GIZ sourcebook called "Valuing the Benefits, Costs, and Impacts of Ecosystem-based Adaptation Measures"

The concept of Ecosystem Based Adaptation is mainstreamed into all relevant sections of the step-by-step guidance on climate proofing infrastructure investments.

3. CLIMATE PROOFING – STEP BY STEP INSTRUCTION

Climate Proofing of infrastructure investments, such as water infrastructure, is a defined transformational pathway towards creating resilience of water infrastructure, a process with multiple feedbacks. The process of climate proofing includes the following steps that occur in various iterations and feedback loops.

Projects undertaking climate proofing under this manual, employ the principles of ISO 31000 Risk Management Standard i.e., ISO 31000 (Risk management) and ISO 31010 (Risk assessment) (ISO, 2009, 2018). The manual at hand has a specific focus on risk assessment and is therefore much more detailed on step 2.

Step 1: Scoping

Step 1 » Scoping

Step 2 » Risk Assessment

Step 3 » Risk Treatment

Step 4 » Monitoring & Evaluation (M&E)

Scoping for climate proofing consists of several activities laid down here. The following activities are important when starting a climate proofing process and apply to all entry points of climate proofing in the infrastructure investment process.

Activity 1 – Defining the objective and context of climate proofing

Context and objective are defined by the different stages of the infrastructure investment cycle, from planning to project identification, preparation, and operation. This may also include future asset planning, prioritizing refurbishment, regulatory or organizational mandate.

Overall, climate proofing objectives may include:

- Climate proofing for development of infrastructure investment policy.
- Detailed planning for proposed Infrastructure.
- Climate proofing as part of a regulatory or funding process.
- Climate proofing of existing infrastructure operations and maintenance policies and procedures.
- Climate proofing for ensuring due diligence in managing and governance of assets.

Depending on these entry points climate proofing could for example focus on infrastructure service reliability, or structural integrity, or economic performance. Whereas climate proofing at the basin level looks at climate change impacts on various systems at the basin level, climate proofing at the level of project preparation focusses on climate change impacts at a particular location informing for example the design aspects of the infrastructure. This implies that objective setting is crucial to set the scene for defining the subsequent approaches for risk assessment and risk treatment. Hence, purpose of climate proofing is different and needs to be stated well in the beginning of every climate proofing process **(For more details see Chapter 4)**.

Establishing the context is usually done by the key stakeholders who should include at least the project owners, relevant regulatory agencies, financing institutions, affected people and affected third party interests.

Activity 2 – Develop and adopt guiding principles

Prior to beginning the risk assessment or climate proofing process, develop and adopt guiding principles for assessing and planning for the effects of climate change. These principles can be used to demonstrate alignment and consistency between policy and plans, but at a minimum should align with those already in place as part of planning efforts. Examples could include, but are not limited to:

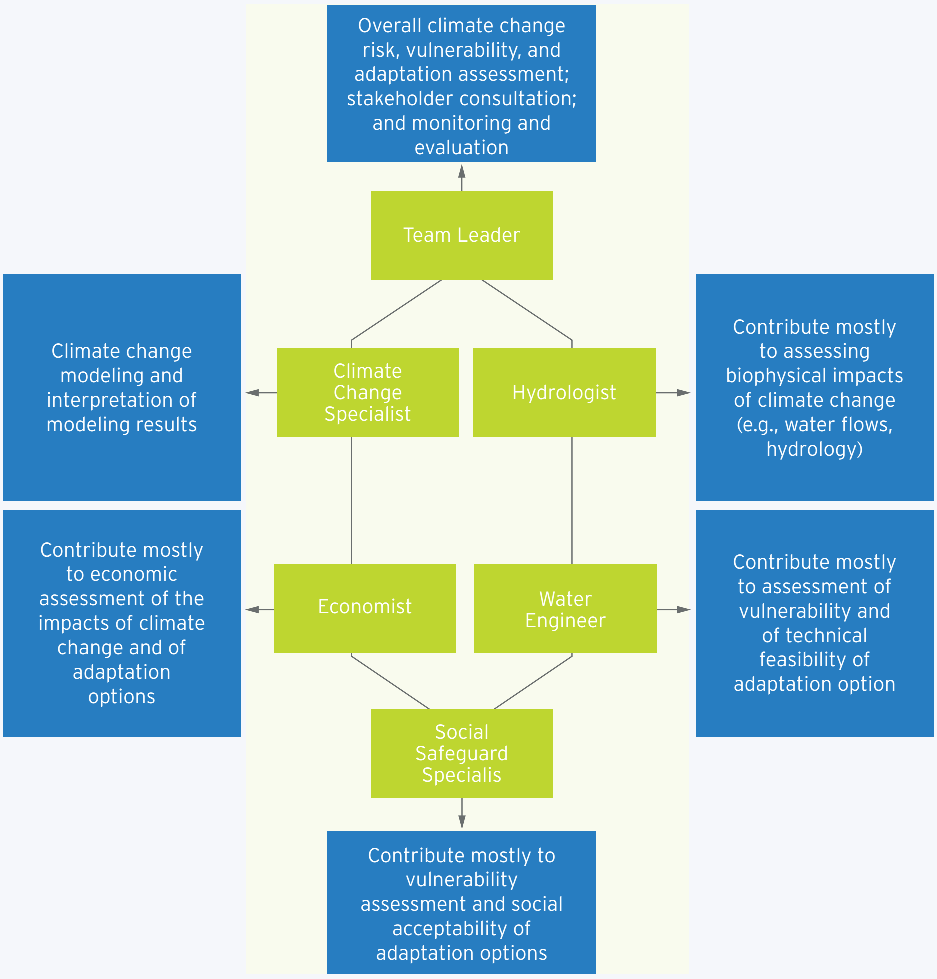
- **Risk-Based:** Aligned with the precautionary approach of managing climate risks and assets. Recognises that addressing climate risk is a responsibility of water infrastructure developers and operators
- **Evidence-based:** Use the best available science and evidence at the time, including common climate projections, and review regularly.
- **Leadership and culture:** Build leadership and enable a culture of everyone taking responsibility; "mainstream" climate change among various staff and decision makers.
- **Partnerships and engagement:** Establish and maintain partnerships that enable broader collective impact and further policy and planning objectives.
- **Aligned:** Align with existing policies, plans and/or initiatives that provide other benefits and have compatible goals and objectives.
- **Adaptive and flexible:** Promote flexible approaches that incorporate the potential for iteration and updates based on best available information, leaving a range for future options.
- **Transparent monitoring and review:** Promote an ongoing process with commitment to review
- **Equitable:** Seeking solutions that equitably address the risks of climate change and share the costs and benefits of action. Be mindful of, and include where appropriate, the unique needs and conditions of people who are most vulnerable.

Activity 3 – Building teams

When undertaking scoping activities related to climate proofing, it is valuable to bring a diverse set of skills, expertise, and experience to identify what climate risks may impact the project and what information is required. Identifying key members of the team is critical. Ideally, a core project team should be created with staff and stakeholders who are infrastructure-focused but also embody diverse backgrounds and provide a range of perspectives. Avoid having a project team consisting of one person, where workload or silos can pose challenges in implementation. In other words, involve infrastructure focused staff, but broaden the team out as much as possible. Consider how and to what extent stakeholders and engagement needs to factor into your process. Stakeholders have different interests and influences when undertaking a Climate Risk Management process related to infrastructure. It is critical that external stakeholders and partners understand and buy-in to the results from this process to invest and ultimately build resilience down the road.

In establishing the climate proofing team, it is important to consider roles and competencies. Figure 8 schematically illustrated types of stakeholders and their specific roles.

Figure 8 Stakeholder involvement in Climate Proofing



- **Risk Assessment Specialists:** In-depth knowledge of the fundamentals of risk. They have strong skills in facilitation and communication that strengthen the knowledge and expertise of other team resources and guide the process.

- **Climate Specialists** have a strong understanding of climate that is relevant to the local context. They can interpret climate data and communicate uncertainty effectively with other team resources.

- **Planning Individuals or groups** with knowledge of community planning, land-use planning, infrastructure planning and other related expertise relevant to the scope of the assessment (like transportation) can provide a broader understanding of multi-stakeholder goals and relevant policy.

- **Infrastructure Experts** (Technical and Engineering): Technical or engineering subject matter specialist(s) have relevant experience working with the infrastructure or systems being assessed.

- **Environment Expertise** needed will vary depending on the assessment scope but can include knowledge on topics like sustainability, hydrology, landscape architecture, ecology, aquatic biology, or forest management.

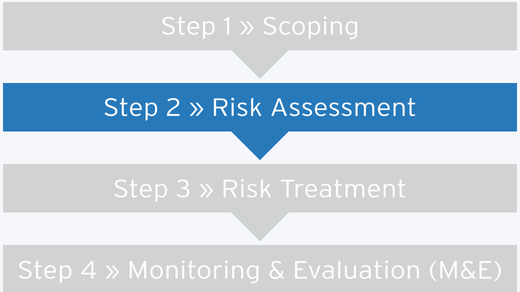
- **Operation & Maintenance:** Can provide valuable insight into the system being assessed or similar systems they have worked with previously.

- **Management, Finance:** Can assist with encouraging buy-in across the organization and aligning project objectives with the organization's goals and strategy.

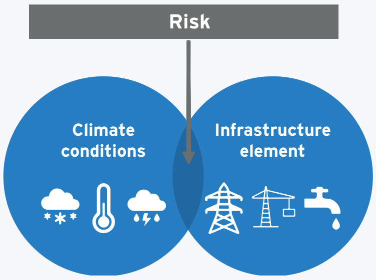
- **Legal, Insurance:** Can provide insight on topics like liability, risk tolerance, the ability to acquire insurance, and relevant policy.

- **People:** Non-organizational stakeholders who rely on the services of the systems or assets being assessed have critical perspectives to contribute related to service disruptions and levels.

Step 2: Risk assessment and evaluation



To identify appropriate climate risk treatment measures, those climate risks and their causal structure need to be identified that are likely to reduce the service reliability, structural integrity, and safety, as well as the economic performance and overall feasibility of existing and new infrastructure projects. Thereby, understanding projected climate change and its impacts on the hydrology and grey infrastructure considering local environmental conditions is key to identify the relevant risk treatment options to arrive at water infrastructure resilience.



There are many different methodological approaches to undertake climate risk assessments depending on its scope. Differential modifications for different stages in the infrastructure planning process, as well as for new and existing infrastructures are detailed in Chapter 4. Though, the following generic approach adopted and contextualised by the NBI is based on the Public Infrastructure Engineering Risk Assessment Protocol (PIEVC) that applies to all types of risk assessments.

Thereby, NBI's risk assessment methodology conforms to all main principles of the ISO 31000 Risk Management Standard.

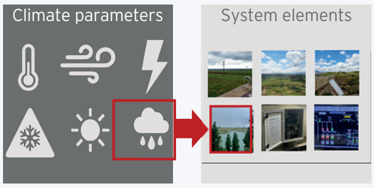
A key output of risk assessment following the principles of PIEVC is a metrification of risk using a configured risk matrix that is composed of a climate likelihood and impact scoring process determined by defined scales and data analysis on the climate and the infrastructure side. Depending on the scope and objective of the assessment scoring class definitions and the metrics can take various shapes and that need to be defined through a process of various iterations explained in this guideline. The common ground, though, is the overall formula used to calculate risk values which is:

INFRASTRUCTURE RISK (service reliability, structural integrity, economic viability…) =
Exposure x Likelihood (hazard) **x Impact** (vulnerability)

The output generated in this step is the calculation of risk values e.g., for different infrastructure structural, operational, or service-related elements using the formula.

Figure 9 PIEVC framework for risk assessment

Exposure (Ex) Assessment: Does the reservoir "feel" rain? "yes" /"no"



Likelihood Scoring (Climate Service)

Likelihood Scoring Level	Description
0	Negligible / Not Applicable
(1)	Highly unlikely / improbable
(2)	Remotely possible
(3)	Possible / occasional
(4)	Somewhat likely / normal
(5)	Likely / frequent

Impact scoring (vulnerability assumptions)

Impact scoring level	Description
(1)	Insignificant
(2)	Minor
(3)	Moderate
(4)	Major
(5)	Extreme

Risk calculation and matrix completion

System elements	Extreme Flood (PMF)				Safety Check Flood (10,000yr)			
	8,000m' /s				3,000m•Js			
	P score =			5	P score =			6
	Ex	L	I	R	Ex	L	I	R
Structures								
Dam								
Gated spillway	Y	1	5	5	N			
Dam crest	Y	1	5	5	N			
Settling basin	Y	1	5	5	Y	2	4	8
Reservoir	Y	1	5	5	Y	2	5	10
Powerhouse								
Turbines	N				N			
Generators	N				N			
Erosion Protection	Y	1	5	5	Y	2	5	10
Operations								
Releasing floods-high flows gates	Y	1	5	5	Y	2	2	4
Monitoring water levels	Y	1	5	5	Y	2	4	8
Maintenance & procedures	Y	1	5	5	Y	2	4	8
Personnel	Y	1	5	5	Y	2	4	8
Services								
Hvdropower	N	1	5	5	N			
Irrigation	Y	1	5	5	Y	2	3	6
Water supply	Y	1	5	5	Y	2	3	6
Flood management	Y	1	5	5	Y	2	5	10

Risk evaluation and implications for adaptation

Impact					
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2 (Score = 2)	2	4	6	8	10
1	1	2	3	4	5
Likelihood	1	2	3	4	5 (Score = 5)

Low
No or minimal action

Medium
Action may be required

High medium
Review risk sensitivity

High
May require high-priority action

The calculation of risk values depends on exposure analysis applying a binominal approach (yes/no) as well as discrete metrics applied for assessing likelihood and impact. Here, PIEVC recommends using a 5 scale approach. For calculating aggregated risk values for individual infrastructure elements or services, first the scoring system and the criteria and thresholds for scoring levels for both, likelihood and impact need to be defined. Another important output of the assessment is its evaluation in terms tolerability. Risk tolerance thresholds are being defined (see color coding) that guide defining implications of the calculated risks for a specific element of the infrastructure.

The risk assessment results can be collected a documented in a risk matrix. The number of risk values calculated depends on the number of elements looked at, the number of elements (can be infrastructure components, or specific services under assessment) that were selected to be exposed to the number of climate event types.

Figure 10 Generic description of NBI's Risk Assessment Methodology based on the PIEVC Protocol

Activity 1	Defining objectives, context, scales and elements subject to assessment	
	Task 1 & 2	Establish assessment objectives and context
	Task 3	Select and establish the assessment criteria and scale to be considered
	Task 4	Defining the system and elements under assessment
Activity 2	Determine climate parameters and assess exposure	
	Task 1	Select climate parameters
	Task 2	Assess Exposure
Activity 3	Develop and impact scoring system: Determine impact criteria & impact thresholds	
	Task 1	Determine im act criteria
	Task 2	Define impact scales and corresponding impact thresholds
	Task 3	Define hydrological and climate indicators for impact thresholds
Activity 4	Develop tailored climate data and information products	
	Task 1	Identify Representative Concentration Pathways (RCPs)
	Task 2	Definin timescale of the ro·ections
	Task 3	Develop climate data products
Activity 5	Scoring Likelihood and impact, calculating and evaluating risk	
	Task 1	Defining the probability / likelihood scoring levels and metrics
	Task 2	Score the likelihood climate change
	Task 3	Assess and score the impact
	Task 4	Calculate Risk Score
	Task 5	Evaluate the Risks
Activity 6	Recommendations for risk treatment and reporting	
	Task 1	Prioritise risks based on the risk evaluation
	Task 2	Develop recommendations for next steps. risk treatment and data sufficiency
	Task 3	Develop a report on the risk assessment, evaluation and recommendations

Thereby, collecting and processing climate data include (a) identification of climate parameters, (b) corresponding indicators, (c) define how they might interact with the elements of the infrastructure under assessment and (d) developing climate information products suitable for carrying out the risk assessment. The more data can be collected on the infrastructure the more informed the risk assessment will be. The climate likelihood scoring process can be completed separately from the impact scoring of the risk assessment.

Activity 1 – Defining objectives, context and criteria of the assessment

The objective, context and criteria should be established, reviewed, and documented throughout the entire assessment. They differ between assessments and organizations and will relate to understanding and addressing the risk appetite of the organization. They will dictate the assessment's complexity, the time, resources, and data to complete it.

Task 1 & 2 – Establish assessment objectives and context

The objective of the assessment can be drawn from the objective of climate proofing detailed in Step 1 "Scoping of climate proofing" and will guide establishing the risk assessment approach.

Hence, whether risk assessment is carried out for developing a climate resilient infrastructure investment plan or designing feasible new project or stress test existing infrastructure is a decisive factor that defines the way a risk assessment is configures (compare chapter 4).

Overall, three types of different scopes and context of assessment can be differentiated:

- Understanding the risk of service reliability and performance of the portfolio of newly planned or existing infrastructure, considering different geographies.
- Understanding the risk of structural integrity and operational robustness of the portfolio of newly planned or existing infrastructure, considering different geographies.
- Understanding the economic risk of the of the portfolio of newly planned or existing infrastructure, considering different geographies.

Sometimes, all objectives might be covered in a single assessment, the scope opens wide then, or there is a particular interest in one of these that allows for more in-depth assessment using specialised techniques.

Questions to be addressed related to objective:

- Is the element, and its sub elements, relied upon for delivering services across a jurisdiction?
- In the event of a climate impact would damage and/or loss of function to the element cause concern for public safety?
- Has the element, or any of its sub elements, previously been defined as critical via government processes or otherwise?
- Is the element, or any of its sub elements, not necessarily owned or maintained by the risk assessment lead but still considered important by stakeholders and residents (e.g., cultural heritage)?

Box 3 Example of objectives and context of dam infrastructure assessments

Example 1: Assessing structural integrity as an objective: Hydrological safety assessments are necessary to prevent a failure of water infrastructure, in particular dams. Results of the hydrological safety assessment are necessary inputs for the geotechnical safety assessments, which consider the stability of the dam against sliding, turning, base failure. All assessments feed into to design of a water infrastructure or help devise rehabilitation measures in case safety standards are not met. Specifically, dams require a comprehensive safety assessment. The hydrological dam safety analysis consists of three pillars: hydrological modelling, regionalization, and worst case probable maximum flood (PMF)

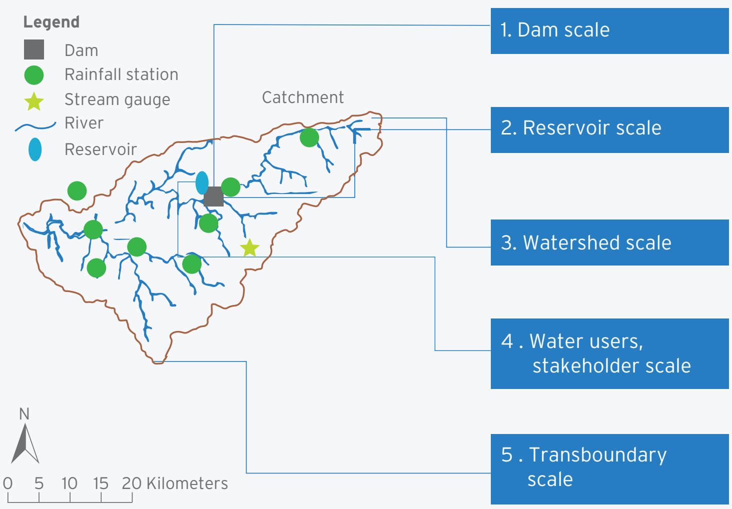
Example 1: Assessing service reliability as an objective: NBI took the lead in executing a service reliability assessment of six infrastructure projects at pre-feasibility and feasibility stage from the NEL Investment Programme (NELIP). Due to the important services which serve as main objectives of the projects, it was necessary to study the effects of climate change on the hydrological regiment in the respective rivers to be able to assess the risk on the reliability of the provided services. The relevant infrastructure services of these projects were hydropower, municipal and industrial water supply, irrigation, flood control and e-flow.

Task 3 – Select and establish the assessment criteria and scale to be considered

Assessment criteria will identify key details for the assessment. These include:

- Asset details and boundary conditions
- Level of service standards
- Importance or criticality of assets and sub elements
- Time horizon of the assessment
- Geography or geographies of a portfolio (considering different climate regions)
- Governance and jurisdictional considerations
- Assessment process selection or screening

Figure 11 Example of Risk Assessments levels



An important decision needs to be taken about defining the scale of the assessment. For water infrastructure the scale could be for example, the transboundary, watershed, reservoir, dam, and the water user's scale. Depending on the assessment objective and context the scales are defined. To assist in this process, decision making tools guiding the process include multi factor analysis, SWOT, surveys, etc.

Task 4 – Defining the system and elements under assessment

Based on the decided scope, criteria and scales of the assessment, it is important to identify, agree and document the specific elements of the system decided upon. As part of undertaking any assessment, it is important to identify and document the elements of a system or portfolio that may be vulnerable to the impacts of climate-related hazards.

System elements	Climate parameters / hazards							
	Climate parameter A				Climate parameter B			
	Indicator				Indicator			
	L score =				L score =			
	Ex	L	I	R	Ex	L	I	R
Structures								
Dam								
Elements x, y, z								
Hydropower								
Elements x, y, z								
Operations								
Elements x, y, z								
Services								
Elements x, y, z								

This process should be holistic and systematic to ensure critical elements are not mistakenly excluded from the assessment. Of course, the final elements of a particular risk assessment will differ depending on the scale, intended, or provided service, geographic context and assets owned, operated and/or managed that are of interest.

For example, at a municipal level, one could envision aligning these elements under assessment with the services provided to residents across the municipality as well as other elements that are particularly important for providing a continued level of service under climate change and extreme weather events. Table 1 describes categories of elements that may be assessed. Risk assessment managers and facilitators are encouraged to review and identify together with stakeholders those categories that may be particularly relevant based on the objective of assessment, and the local geographic contexts.

Table 1 Type of elements that can be subject to assessment

Infrastructure services	• Hydropower generation • Flood control • Irrigation • Municipal and Industrial water supply (M&I) • Economic viability
Infrastructure assets and their structural components	• Built infrastructure: Buildings, transportation infrastructure, energy and electrical infrastructure, water resources and drainage, water supply, treatment, communication infrastructure, etc. • Natural environment: green infrastructure, natural assets, soils, tree canopy, bioswales, land use etc.
People	• Employees of an organization, also includes contractors, vendors, clients, customers, and other people that the organization chooses to classify in this category. In general, the term includes internal and external stakeholders of the organization that may be directly affected by the organization's risks and adaptation measures.

The elements selected are documented in the risk matrix spreadsheet, illustrated in figure 9. Often a categorization like Table 1 suggested is necessary.

Activity 2 – Determine climate parameters and assess exposure

Task 1 – Select climate parameters

This task is used to establish the climate parameters or hazards relevant for the infrastructure elements defined. Selecting climate parameters of measurable climate conditions, such as temperature, precipitation, and wind are a starting point for the definition of climate indicators. Though first a kind of exposure analysis needs to be conducted following the question: Does a particular element of the infrastructure feels a specific climate event?

Box 4 Definition and difference between climate parameter and indicator

As noted, the terms climate parameter, climate hazard, and climate hazard indicator are central to the risk assessment process. Parameters describe the overall climate "categorization", whereas the hazards and indicators describe more specific impactful events and the intensity thresholds at which impacts can be expected to occur on the elements under assessment.

For the purposes of this manual, climate parameters and indicators are defined as:

"The broad categories or groupings of measurable climate conditions, such as temperature, precipitation, and wind, among others. The terms climate hazards and indicators refer to the more specific impactful events that are likely to interact with a given asset or portfolio and its service and create a measurable impact that can be described either quantitatively or qualitatively."

At this stage of assessment, it is sufficient to understand the climate parameter relevant for the assessment. Later, when infrastructure thresholds are established (following tasks), the corresponding climate indicators can be defined (task 4).

Selection of relevant climate parameters

	Climate parameters / hazards							
System elements	Climate parameter A				Climate parameter B			
	Indicator				Indicator			
	L score =				L score =			
	Ex	L	I	R	Ex	L	I	R
Structures								
Dam								
Elements x, y, z								
Hydropower								
Elements x, y, z								
Operations								
Elements x, y, z								
Services								
Elements x, y, z								

Those climate parameters are to be selected that are most common in the geographic area of concern and that is associated with the potential malfunction, failure of its structure or serviceability (Examples of combination events include rain, high temperature coupled with high humidity, etc.).

- When it comes to the **structural integrity** one must specifically consider extreme climate events, such as for temperature and precipitation.

- When it comes to **infrastructure services**, one must consider the hydrological regime and what a change in river flow can impact these services. An increase in reduction of discharge can impact hydropower production, water supply for irrigation/municipal or industrial use, flood protection and e-flow dynamics.

Table 2 shows an example of climate parameters. In Annex 5.7 a full list of climate parameters can be found for orientation. This includes any combination of climate hazards.

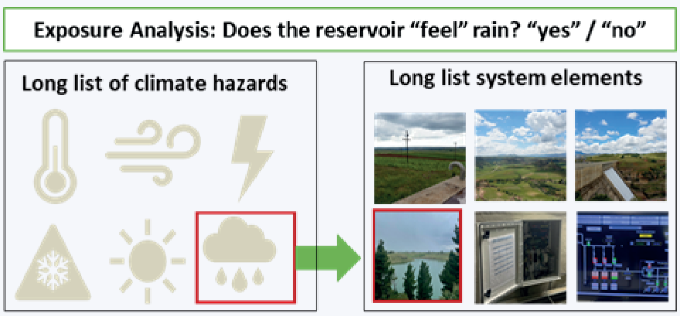
Table 2 Example of climate parameters and hazards to be selected, extensive list in Annex 5.7

Climate parameter	Climate events	
Temperature related hazards (extremes, heat spells, change in season, etc.)	Extreme high temperatures	
	Periods of high temperatures (heat spells)	
Rainfall related hazards (heavy rain, change in seasons, droughts, etc.)	Extreme high rainfall events (heavy rain)	
	Periods of high rainfall (prolonged rainfall)	
Hydrological hazards (floods, low flows, water temperature, material concentrations)	Flood	High water levels
		High flow velocities
		High water volumes
	Period of high discharge	
	Surface run-off	
	Low flow	Low water levels
		Low flow velocities
		Low water volumes
	Period of low discharge	

Task 2 – Assess exposure of elements to climate parameters

Not all infrastructure elements usually interact with a types of climate parameters. The risk matrix provides an opportunity to flesh out which of the elements listed previously would "potentially" feel the hazard. For example, does monitoring equipment "feel" lightning? Does the reservoir "feel" rain? Does underground infrastructure "feel" wind? If there is no potentially connectiveness between an element and a particular climate hazard, then there is no need to further do likelihood, impact and risk analysis for that element.

Figure 12 Exposure analysis using the risk matrix



System elements	Climate parameters / hazards							
	Climate parameter A				Climate parameter B			
	Indicator				Indicator			
	L score =				L score =			
	Ex	L	I	R	Ex	L	I	R
Structures								
Dam								
Elements x, y, z	1				0			
Hydropower								
Elements x, y, z	0				1			
Operations								
Elements x, y, z	1				1			
Services								
Elements x, y, z	1				0			

It is important to note down in the risk matrix using a Yes / no analysis. With this first order screening those elements are considered for further analysis that are deemed to be exposed to a given hazard.

Activity 3 – Develop an impact scoring system: Determine impact criteria & impact thresholds

This activity prepares for likelihood and impact scoring. For likelihood scoring first the climate indicators (a defined certain flow for example) need to be defined that would result in a specific service loss, like hydropower, or structural damage to dam elements. Hence, as a bottom-up approach is followed, first the impact dimensioning is established before the likelihood.

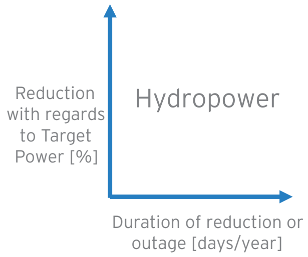
Introduction: Impact assessment / scoring is based on vulnerability assessment to a selection of defined climate hazard indicators to which the system is exposed to and needs to be defined based on the objective of the assessment (e.g., service reliability, or structural integrity). Impact analysis determines the nature and type of impact which could occur if an event, situation, or circumstance has occurred. The impact on the infrastructure structural integrity or service reliability is related to the impact of climate change on the current design's capacity and key socio-economic assumptions to achieve or not achieve the project objectives (energy production, social, environment and safety). An event may have a range of impacts of different magnitudes and affect a range of different objectives and different stakeholders. Impact analysis can vary from a simple description of outcomes (suited for Initial Analysis /High level Risk Screening) to detailed quantitative modelling or vulnerability analysis (suited for CCRA).

Task 1 – Determine impact criteria

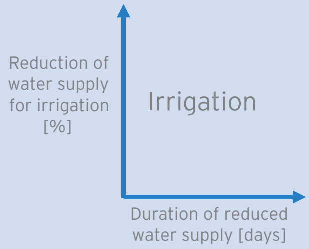
In this manual the focus is rather on hydrological variables taken as example. Depending on the infrastructure being assessed and the services it provides one can define one or multiple aspects to be evaluated. For **hydropower, e-flow as well as water supply** the aim is to ensure continuous provision of the service without reduction of hydropower generation or water supply. Hence the criterion can be defined as **"reduction of produced power"** and the **"amount of time of reduction"**. For the **flood control service**, the degree of the **"hazard" (flood)** created due to a certain water level as well as the degree of **"exposure"** of the population upstream and downstream of the infrastructure are relevant. For "**structural integrity"**, the **"load exceedance"** due to a climate or hydrological pressure, as well as **"increased maintenance and operational costs"** is in focus of the assessment.

Though, there is a close relationship between structural integrity and service reliability, climate risks and impacts can be assessed solely for service reliability if the focus is on anticipated changes of water amounts relevant for the service. Structural integrity assessments focus more on extreme events that could pose a threat to the entire infrastructure system. Box 5 describes the impact criteria for all types of services and structural integrity of the infrastructure.

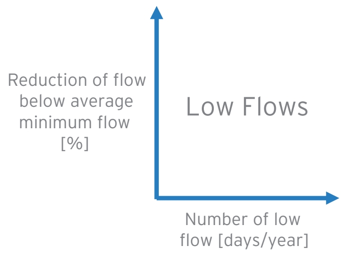
Box 5 2-factor criteria for impact assessment of service reliability and structural integrity



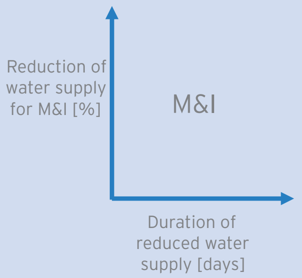
Climate change impact on Hydropower can be defined as the reduction of targeted power within a defined timeframe of outage.



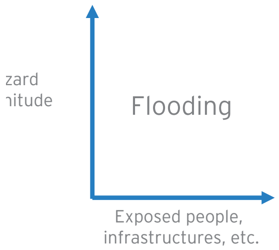
Climate change impact on water demand for irrigation can be defined as the reduction of supplied water within a defined timeframe of reduction.



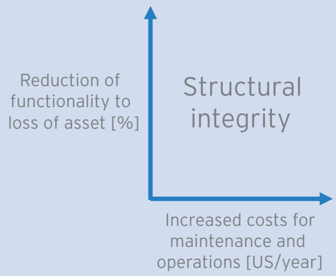
Climate change impact on e-flow can be defined as the change in discharge regime for a defined number of days.



Climate change impact on water demand for municipal and industrial use can be defined as the reduction of supplied water within a defined timeframe of reduction.



Climate change impact on flood protection capacity can be defined as an increased hazard caused by higher water levels that the dam was designed for or is operated with.



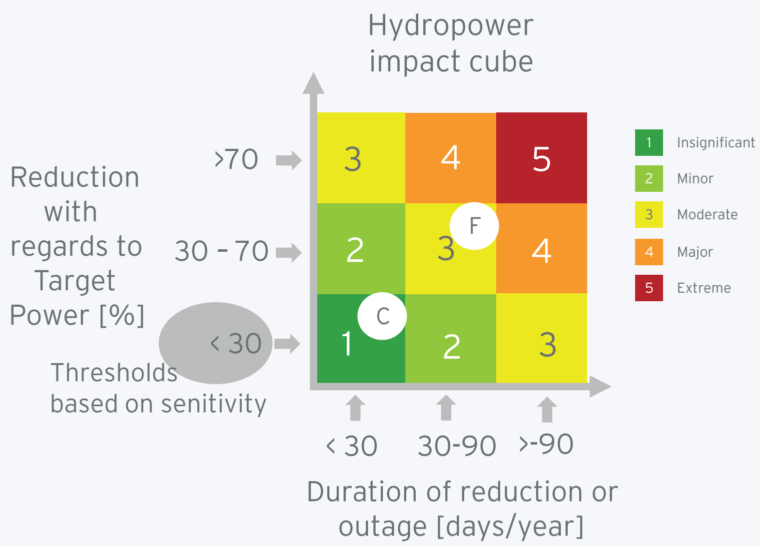
Climate change impact on the structural integrity of the infrastructure can be defined as exceedance of the load capacity of the physical component (e.g. spillway, dam crest) leading to loss of function, damage to and loss of the asset, as well as increased cost for operations and maintenance.

Task 2 – Define impact scales and corresponding impact thresholds

The criteria developed in task 2 need to be transformed into measurable impact severity units for the risk assessment. The corresponding impact severity scale should extend from the maximum credible to the lowest impact of concern. **The scale may have a numeric scale e.g., 1 – 5,** as defined by the PIEVC matrix.

The scale is characterised through different classes of impact severity, that need to be established by the definition of impact thresholds that are connected to the degree of sensitivity of the service beneficiary system to suffer harm or impact from the climate event types selected. **Defining those thresholds are based on sensitivity / vulnerability considerations** (example: crop water demand threshold, minimum power generation requirement depending on economic and human needs etc.).

Figure 13 Example of a risk cube parameterization



The impact thresholds can be generic, such as the defined number of days with service reduction or percentage of reduction compared to a key demand. Where to set these thresholds for developing a scale from 1 – 5 requires some effort, as these thresholds must be linked with meaningful impacts resulting from sensitivities. The more information on sensitivity (e.g., capability to live with power shortage) is provided the more specific they can be defined.

For parametrization, when the duration of service reduction is considered one can either take continuous days or average days per time-period into account. In the following some specific considerations for the different services and structural elements of infrastructure are described.

- **Hydropower:** Water demand for producing electricity via a power plant which is located on or near a water source. The function of the power plant is converting the energy from potential energy (water flow – change in water elevation) to electrical energy. The greater the water flow and the higher the head, the more electricity the plant can produce. Due to climate change the discharge in a river can increase or decrease, leading to a reduction in hydropower efficiency. The **thresholds** for defining the degree of impact severity depend on the capacity of energy users to live with power outage and the types of consequential effects.
- **Irrigation**: Water demand for agriculture use by applying various artificial systems of tubes, pumps, and sprays. The system is usually applied in the areas where rainfall is irregular, drought events or arid climate regions. A reduction in water supply for irrigation can lead to loss of crops (food insecurity) and unemployment. The thresholds for defining the degree of impact severity can depend on the crop water requirement, the time of year or merely on the percentage of reduction of supply with regards to the demand.

- **Municipal/Industrial Water supply:** Municipal water demand includes water for drinking, cooking, washing, laundering, and other household functions. Industrial demand includes water for stores, offices, and manufacturing plants. A disruption or reduction in water supply can lead to a decrease in quality of life as and economic deterioration. The **thresholds** for defining the degree of impact severity can depend on the degree of reliance citizens have on water, the reduction that certain industries can sustain or simply a percentage of reduction with regards to the demand.

- **Flood management:** Governance bodies introduce flood policies and managements plans to mitigate and adapt the flood periods. Dams can store higher river discharges to protect the downstream catchments from flood. Increased floods caused by climate change could require higher dam storage capacity or an optimization of reservoir operation plans. The **thresholds** for defining the degree of impact severity depend on the exposure of upstream and downstream flood plains. Different definitions of exposure can come into play such as: population density, investment projects.

- **Low flows**: A minimum monthly average flow is required to sustain river ecosystems and continuity of navigation. Changing river flow dynamics can affect ecosystems and navigation negatively. The **thresholds** for defining the degree of impact severity depends on the available ecosystems and navigation requirements.

- **Structural integrity:** The thresholds for defining the degree of impact severity depend on the structural configuration of the infrastructure, e.g., their age, materials used, maintenance is executed, operations are implemented etc. for planned infrastructure feasibility studies and codes and standards provide an insight into impact thresholds, such as design standards.

Examples of impact thresholds and the impact scoring for different services of the six case studies is presented in the following Table 3.

Watch out!!! The definition of the thresholds (percentages) presented in the table are examples only. Each project should review this table to confirm the values and revise as necessary, based on the risk appetite of key stakeholders.

Table 3 Examples of impact thresholds based on vulnerability considerations for type of assessment objective (service reliability and structural integrity)

Impact scoring levels		Examples of types of impact scales by objective of assessment						
	Service reliability					Structural integrity		
	Hydropower*	Irrigation***	Municipal/Industrial Water Demand	Flooding	Low flows	Physical components	Operation and Maintenance	
1	Insignificant	<30% reduction** in generated power for up to 30 days/year	<30% reduction in water supply for irrigation for up to 14 consecutive days/year	<30% reduction in water supply for M&I use for up to 1-3 consecutive days/year	Water level within flood buffer and exposure low or medium	<30% reduction of flow below mean minimum flow for up to 7 days/year	Virtually no effect on asset condition, no repairs required	< 0.1% increase in (average) annual cost to sustain service levels
2	Minor	<30% reduction** in generated power for 30-90 days/year or 30-70% reduction for up to 30 days/year	<30% reduction in water supply for irrigation for 14-30 consecutive days/year or 30-70% reduction for up to 14 consecutive days/year	<30% reduction water supply for M&I use for 3-7 days/year or 30-70% reduction in for up to 1-3 consecutive days/year	Water level within flood buffer and exposure high or spillway active (frequent flood event 10a) and exposure low	<30% reduction of flow below mean minimum flow for 15-30 days/year or 30-70% reduction for up to 7 days/year	Minor damage to asset requiring 0- 5% of annual maintenance budget for repairs	0.1-1% increase in (average) annual cost to sustain service levels
3	Moderate	<30% reduction** in generated power for >90 days/year or 30-70% reduction for 30-90 days/year or >70% reduction for up to 30 days/year	<30% reduction in water supply for irrigation for >30 consecutive days/year or 30-70% reduction for 14-30 consecutive days/year or >70% reduction for up to 14 consecutive days/year	<30% reduction in water supply for M&I use for >7 consecutive days/year or 30-70% reduction for 3-7 consecutive days/year or >70% reduction for 1-3 consecutive days/year	Spillway active (frequent flood event 10a) and exposure medium or spillway active (rare flood event 50a) and exposure low	<30% reduction of flow below mean minimum flow for >30 days/year or 30-70% reduction for 15-30 days/year or >70% reduction for <7 days/year	Moderate damage to asset requiring 6-25% of annual maintenance budget for repairs	2-10% increase in (average) annual cost to sustain service levels
4	Major	30-70% reduction** in generated power for >90 days/year or >70% reduction for 30-90 days/year	30-70% reduction in water supply for irrigation for >30 consecutive days/year or >70% reduction for 14-30 consecutive days/year	30-70% reduction in water supply for M&I use for >7 consecutive days/year or >70% reduction for 3-7 consecutive days/year	Spillway active (frequent flood event 10a) and exposure high or spillway active (rare flood event 50a) and exposure medium	30-70% reduction of flow below mean minimum flow >30 days/year or >70% reduction for 15-30 days/year	Major damage to asset requiring 26-80% of annual maintenance budget for repairs	11-30% increase in (average) annual cost to sustain service levels
5	Extreme	>70% reduction** in generated power for >90 days/year	>70% reduction water supply for irrigation for >90 consecutive days/year	>70% reduction water supply for M&I use for >90 consecutive days/year	Spillway active (rare flood event 50a) and exposure high	>70% reduction of flow below mean minimum flow for >30 days/year	Extreme damage to asset (e.g. design flood) requiring > 80% of annual maintenance budget for repairs	>40% increase in (average) annual cost to sustain service levels

*Evaluation depends on the available energy sources that can cover the demand
**with regards to the target power
*** growing stages of crops and soil characteristics are not considered in the evaluation

Task 3 – Define hydrological indicators and climate indices

After having established the impact thresholds for the different scales of severity, task 3 dedicates to defining the corresponding climate or/and hydrological conditions, such as magnitudes of flows, that result in the defined impact for each impact severity class illustrated above.

For example:

- What is the climate indicator that would impact the structure of the asset in focus of assessment in a moderate way, defined in table 3 as the "damage rate to asset requiring 6-25 per cent of annual maintenance budget for repairs"?
- What is the climate indicator that would impact hydro power generation reliability of the asset in focus of assessment in a moderate way, defined in table 3 as "<30 per cent reduction** in generated power for >90 days/year or 30-70 per cent reduction for 30-90 days/year or >70 per cent reduction for up to 30 days/year"?

Table 4 shows flow indicators for extreme impacts, such as overtopping the dam, spillway failure or flood control. These standard structural design thresholds and indicators need to be aligned with the impact class definition illustrated in Table 3. Probable Maximum Flood, safety check flood and design flood are those performance thresholds that a Multi-Purpose Dam System is usually prepared for. Their exceedance would certainly be associated with the impact class "severe". Climate change can modify flow conditions and their frequency of occurrence implying the need for structural adjustments.

Table 4 Standard structural design thresholds and indicators

Hydrological Indicators representing structural impact thresholds for extreme impact (water shed specific)	
Extreme flood (Probable Maximum Flood) causing overtopping and dam failure	e.g., flow of 8,000 m3/sec
Safety check flood (10,000-year flood) is the threshold for spillway failure	e.g., flow of 3,000 m3/sec
Design flood is the threshold for which flood control is provided	e.g., flow of 2,000 m3/sec
5-year flood	e.g., flow of 550 m3/sec

Table 5 Service reliability thresholds and indicators

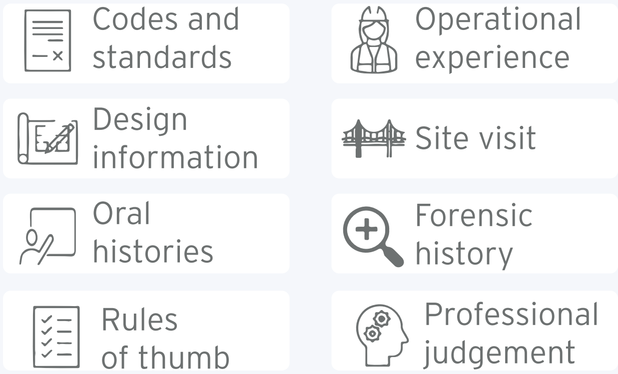
Hydrological Indicators representing structural impact thresholds for extreme impact	
Target hydropower expressed in Power (MW) or head (m)	Flow of xxx as per feasibility
Irrigation demand (depending on crops and size of land)	Flow of xxx as per feasibility
Municipal and industrial water demand (depending on economic dev. and population growth)	Flow of xxx as per feasibility
Flood control level (Spillway level/Dam crest level)	Water level in masl as per feasibility
Average monthly minimum flow	Flow of xxx as per feasibility

Box 6 Design Flood as a performance metric

An example of a performance metric is the design flood for a project. A dam may for example be designed for a T=1000-year flood (Q1000) based on its consequence class (i.e., Qdim =QT). The consequence class is usually based on safety considerations in case of a dam break. This is usually decided based on analysis of historical flood data, reservoir size, dam break analysis, potential damages, and loss of life in case of a dam break. Different countries may have different specifications for how to determine the dam class and the design flood. With climate change, the T-year flood (QT) may change in magnitude for a given time-horizon (e.g., 2080 – 2099) compared to the historical magnitude. In this case the QT flood is the threshold which, if exceeded, could lead to structural failure or flooding. The climate risk assessment documents the likelihood of this happening (based on analysis of climate data) and the severity/consequence should that happen. The product of the severity and likelihood is the risk. Depending on the type of climatic event or series of events most apt to result in the most extreme flooding, the climate work behind this may be complex and / or reflective of considerable uncertainty that should be well understood and explained. Likelihood/probability of exceeding the design flood can be estimated from statistics of ensembles of flood calculations for a given time horizon. At this stage, the analysis must be simple and should employ the simplest approach for climate data, for example a simple version of the delta change method. The classical delta change method transforms the historical data by making use of the changes in mean values. For flood risk assessments, for which extreme precipitation events are very important, the changes in the extremes, which may be different from those in the mean, should be considered as good as possible. Qualified hydrologists, climatologists and or statisticians should carry out the task of generating the required ensembles. Once the ensembles of precipitation and temperature are established, they can be used in a model to generate projections of runoff. The projections are subjected to extreme value analysis to determine the QT flood. The resulting ensemble of QT values are subjected to a further analysis to determine the probability of exceedance of the design flood (Qdim) across the multi-model ensembles. The computed probability can be used to score the likelihood. Quantitative methods can be used here. The data is fitted to a distribution and a probability of exceedance computed. Alternatively, stakeholders may decide on a qualitative likelihood scoring. To evaluate the consequence of exceeding the threshold, the likely consequence of exceeding the flood design should be considered in terms of damage and impact on the project objectives. The scoring is qualitative and must be agreed by the stakeholders. A similar approach may be applied to all the other identified stressors, project performance metrics and thresholds.

To arrive at an understanding of impactful climate and hydrological events and to define impact severity levels corresponds, understanding the load capacity of the elements under assessment is critical that may be based upon codes of practice, design standards, forensic history (past impacts to the infrastructure), constructed design values, rules of thumb, engineering guidelines, operational and maintenance standards, or factual procedures of existing infrastructures in operation, professional judgement and experience, or other relevant information.

Figure 14 Sources of understanding load capacity



Also, forensic analysis of the impacts experienced from past critical climate events is a valuable source of information. Especially, when conducting risk assessments of existing infrastructure, the type of load that revealed a specific damage or service loss might be different from design loads, due to aging of structural components and the way how operations and maintenance had been executed in the past.

Hence, sufficient time should be allocated for data collection. Often data are not publicly available, the buy-in from authorities needs to be established through active stakeholder involvement throughout the assessment process.

- **Sector specific and public authorities** often own considerable data on the infrastructure or the system in focus of assessment. These can include feasibility reports, design standards, Environmental Impact Assessments (EIA), watershed / catchment management plans. But also, data from infrastructure operators that are an important source of data, including incident records, operational rules, bathymetric surveys of the reservoir, inflow-outflow records.

- **Local knowledge filtered through the overall expertise of the assessment team can help compensate for data gaps and provide a solid basis for professional judgment**. Local knowledge can provide insight about the nature of previous climatic events, their overall impact in the region and approaches used to address concerns. In addition, where possible, traditional knowledge, the collective knowledge of traditions used by Indigenous groups to sustain and adapt themselves to their environment over time, should be considered based on the objectives of the assessment.

- Often, local knowledge is gained through site visits to inspect and become familiar with the elements being assessed. These visits offer the opportunity to view facilities and pose questions to local maintenance, operations, and management staff, who can offer insight on the effects of events and remedial actions that may not have been fully captured in incident reports. While not every risk assessment may offer the opportunity to conduct site visits, it is important to gather as much local knowledge as possible through meetings and other consultations. Interviews and reviewing site photography are other approaches that can be employed in addition to or in replacement of a site visit.

Table 6 Examples of knowledge on the elements under assessment for defining performance thresholds

Example of knowledge needed for defining performance thresholds of the structural integrity of dams for selecting climate indicators
• Conditions of the physical infrastructure to determine load capacity • Experienced operational and structural performance of dams under conditions of extreme events • Factors and drivers contributing to sedimentation of the reservoir • Record of damages occurred • Dam safety plans

Be sure to provide robust justification or rationale where possible for the chosen impact threshold. With this information the corresponding climate indicator needs to be defined.

Table 7 Examples of climate event types and corresponding criteria for which thresholds need to be defined

Climate event types	Climate events	Specifications / definitions	Parameter (P), Analysis (A), Unit (u)
Temperature related hazards (extremes, heat spells, change in season, etc.)	Extreme high temperatures	Short-term (day) occurrence of critically high air temperature (max values)	P: Air temperature A: max values U: [°C]
	Periods of high temperatures (heat spells)	Period (days-weeks) of critically high air temperature (high-max values)	P: Air temperature A: #days > max threshold U: [°C]
	Warm season	Season (months) of critically high mean air temperatures	P: Air temperature A: mean, mean max. values U: [°C]
	Extreme low temperatures	Short-term (day) occurrence of critically low air temperature (min values)	P: Air temperature A: min. values U: [°C]
	Periods of low temperatures (cold spells)	Period (days-weeks) of critically low air temperature (low-min values)	P: Air temperature A: #days < min threshold U: [°C]
	Cold season	Season (months) with critically low mean air temperatures	P: Air temperature A: mean, mean min. values U: [°C]
	Extreme temperature oscillations	Short-term (day) extreme oscillation of air temperature	P: Air temperature A: min.-max. diff. U: [°C]
Lightning	Lightning	Short-term (sec.)	P: lightning A: # lightnings
Rainfall related hazards (heavy rain, change in seasons, droughts, etc.)	Extreme high rainfall events (heavy rain)	Short-term event (minutes-hours) with critically high rainfall (max values)	P: rainfall A: sum/time unit U: [mm]
	Periods of high rainfall (prolonged rainfall)	Period (hours-days) of critically high rainfall (high-max. values)	P: rainfall A: sum/time unit U: [mm]
	Wet season	Season (months) with critically high mean rainfall	P: rainfall A: sum/time unit U: [mm]
	Periods of low/no rainfall (dry spell - drought)	Periods (weeks-months) of critical low or no rainfall (low-min. values)	P: rainfall A: #days no rain/< min. threshold U: [mm]
	Dry season	Season (months) with critically low mean rainfall	P: rainfall A: sum/time unit U: [mm]

Climate event types	Climate events	Specifications / definitions	Parameter (P), Analysis (A), Unit (u)
Wind related hazards (storms – blizzards, tornados, hurricanes; periods of no wind)	Extreme high wind speeds (gusts, storms, tornados)	Short-term events (minutes-hours) of critically high wind speeds (max. values)	P: wind speed A: max. values U: [m/s]
	Wind period	Period (weeks-months) with critically high wind speeds	P: wind speed A: # days > threshold value U: [m/s]
	Periods of low/no wind	Period (weeks-months) with critically low wind speeds	P: wind speed A: # days < threshold value U: [m/s]
	Hurricanes, typhoons, tropical storms, low pressure systems, etc.	Short-term events (hours)	P: Occurrence U: yes/no
Hydrological hazards (floods, low flows, water temperature, material concentrations)	Flood	High water levels	Short-term event (min.-days) with critically high-water levels (max. values)
		High flow velocities	Short-term event (min.-days) with critically high flow velocities (max. values)
		High water volumes	Short-term event (min.-days) with critically high-water volumes (max. values)
	Period of high discharge		Period (weeks-months) with critically high mean water availability
	Surface run-off		Short-term event (min.-days) with critically high-water volumes (max. values)
	Low flow	Low water levels	Short-term event (days) with critically low water levels (min. values)
		Low flow velocities	Short-term event (days) with critically low flow velocities (min. values)
		Low water volumes	Short-term event (days) with critically low water volumes (min. values)
	Period of low discharge		Period (months) of critically low mean water availability

The following indicators provide examples, and indicate a specification that depends on the infrastructure element, component, assessment objectives to be looked at:

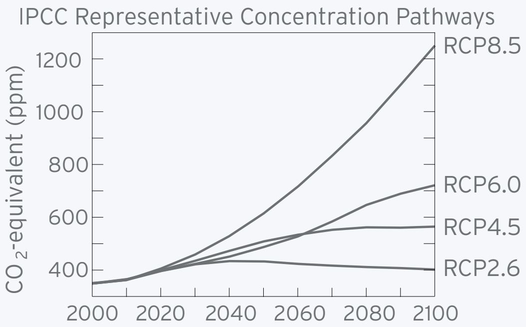
- Annual total wet days precipitation
- Number of days when daily precipitation exceeds 20 mm
- Largest total amount of rain that falls over a period of 5 consecutive days in a year
- Design precipitation (100 year – 24-hour duration)
- Maximum number of consecutive dry days (when precipitation is less 1.0 mm)
- Standard Precipitation and Evapotranspiration index (Characterization of wet / dry day periods over a 24-months timescale)
- 50-year (@10m) return level of annual maximum wind speed
- Lightning, Average number of strikes per year in grid relevant to watershed
- Consecutive wet days
- Very hot days (+30°C)
- Heat waves as number of hot days where maximum temperature is > 90th percentile)

Activity 4 – Develop climate data and information products

This activity carries forward climate event types selected, as well as the climate and hydrological indicators developed based on the impact thresholds discovered through studying the infrastructure system in the previous activities.

Task 1 Identify Representative Concentration Pathways (RCPs) to be used for the projections

Figure 15 Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011)



Use internationally recognised greenhouse gas (GHG) emissions scenarios (concentration pathways), adopted by the Intergovernmental Panel on Climate Change (IPCC). Although there are several GHG scenarios from the fifth assessment report (AR5) of the IPCC, the RCP4.5 moderate GHG emission and RCP8.5 high GHG emissions scenario is commonly used when assessing climate change risks to allow for a conservative assessment of risks posed by the changing climate and to align with current trends in global GHG emissions trajectories. Organizations may choose other scenarios based on their risk appetite, or multiple scenarios based on their project objectives. The choice of RCPs needs to be agreed on by the assessment team based on consensus, as they heavily modify the output of the climate scenarios constructed. Often two RCPs are chosen to be able to compare.

Task 2– Defining timescale of the projections

The assessment team should select the boundaries and time horizons for assessment within the study. Typically, the time horizons for assessment are chosen to align with the design life / expected lifecycle of the infrastructure, or period-of-time before a planned retrofit or reassessment of climate impacts. When applying the risk assessment, the team should use: a **climate baseline** (last 30 years of relevant climate hazard information or 1981 – 2010 normal period). For the assessment of existing projects, the baseline would typically be the climate conditions on which the design was based, or which were prevailing during the period of recent operation. For the assessment of new projects, the baseline represents the climate conditions for which the initial design is made. In many cases, the baseline would be the hydro-meteorological conditions of the most current 30-year period. though, depending on the region and specific location, it has been common practice to base the design of projects in data sparse regions on data for the period 1961-1990, since for this period data of reasonable quality is typically available. This bares a significant risk that the design is inappropriate for the climate and inflow conditions expected for the first 20-30 years of operation, which is typically the period considered in evaluation of economic project performance (e.g. 2021-2050). If there is high confidence in a past trend, it may be reasonable to establish, as a baseline, a 30-year climate trace which is identical to the historical pattern, except with an adjustment to the trending climate variable to better represent current or near-future conditions (e.g. a 30-year climate trace with increased mean daily temperature within the range that might be extrapolated throughout the anticipated lifetime of the project using the current or projected temperature trend). More advisory on collecting historical data can be found here.

- at **least one future climate projection** period for comparison. Several future periods might apply depending on the elements subject to assessment and their defined lifecycle. It is important to consider at least the full range of the current ensemble of climate projections, but care must be taken not to draw unjustifiable confidence around the full bounds of the uncertainty space. The GCM ensemble does not delimit the full universe of possible future climate change. For example, consider using the 10th, 50th and 90th percentile change values (e.g., a reduction in precipitation) from the full range of the latest models (i.e., all CMIP6 models used in the latest IPCC Assessment Report) to achieve a defensible range of plausible future change. Recompute the statistics of key climate stressors both historical and future.

Any **projected values are compared directly to the values established in the baseline** to understand how likelihoods of hazards (individual or combined) are projected to change with respect to current frequency or intensity.

Infrastructure-specific timeframes may also be considered depending on the assessment object and availability and complexity to obtain or develop them. Selection of time horizons should be done in tandem with the risk assessment and engineering teams.

Table 8 Examples of lifecycle of elements

Elements	Expected Lifecycle
Dams / Water supply	• Base system 50 - 100 yrs. • Refurbishment 20 - 30 yrs. • Reconstruction 50 yrs.
Storm / Sanitary Sewer	• Base system 100 yrs. • Major upgrade 50 yrs. • Components 25 - 50 yrs.
Roads / Bridges	• Road surface 10 - 120 yrs. • Bridges 50 - 100 yrs. • Maintenance: annually • Resurface concrete 20 - 25 yrs.
Houses / Buildings	• Retrofit / alterations 15 - 20 yrs. • Demolition 50 - 100yrs.

Defining the timeframes of an assessment involves aligning the expected lifecycle of the elements with climate projections and any data used to evaluate risk. Some suggested lifecycles for infrastructure elements are listed in the Table to the right as a starting point for an assessment.

A more detailed analysis of infrastructure lifecycle is recommended as many factors affect lifecycle. The potential for infrastructure being repurposed, extending lifecycles beyond originally planned timeframes, should always be considered.

Ecosystem Based Adaptation considerations

For ecosystems the baseline differs from grey infrastructure: When Ecosystem based Adaptation (EbA) interventions are utilised, deterioration timelines for natural assets will likely differ from those for built/grey infrastructure. For example, a constructed side channel may have a longer projected lifespan than a dam. This longevity of natural assets compared to build/grey assets is one of the attractive features of EbA – it can often rely on "free" natural processes for maintenance over time. However, not all EbAs will achieve total independence, or they may require many years to do so (ADB 2019). The side channel may need to be regularly dredged to maintain service provision.

Task 3 – Data preparation and projections of extreme events

Careful evaluation of any data used within the PIEVC should be completed during this portion of the analysis, particularly around data availability for complex parameters (e.g., wind gusts, extreme and complex precipitation events). From an analysis perspective, missing data should not deter the inclusion of relevant climate parameters, rather, it may require the use of alternative data sources or datasets (e.g., previous analyses, research papers, specialised studies, or/and global datasets), or less spatially explicit information (e.g., general findings of IPCC assessment reports applicable to the broader region), or expert opinion to conduct the climate analyses.

When the risk assessment is applied to an asset in the design phase, historical climate of the site or region and prior impacts of climate on similar existing assets should be considered. Where historical daily observed data is less available and contains gaps, the team climate specialist should consult multiple data sources to develop a historical baseline for likelihood scoring. Different observation datasets can be obtained from NBI such as DST-FAO and its Integrated Knowledge Portal (IKP) datasets. At the screening level, it may be possible to use pre-set climate indicators available from a series of climate portals.

Things to consider:

- For each climate hazard indicator, determine whether an annual occurrence, or occurrence over the study time horizon, is of most concern. For example, extreme rainfall events may cause recurring flooding issues whose risk would be more usefully evaluated based upon the annual probability of occurrence.

- On the other hand, organizations should also consider the risks of extreme, rarer but more devastating events. It is important to note that climate models may not be able to defensibly support estimates of future changes in the frequency or intensity of phenomena such as tornadoes and that other techniques may be required to arrive at such estimates.

- For these types of events, the low annual probability of occurrence in any given year is less telling but knowing about whether it could occur at least once over the study time would retain it within the organization's understanding of its risks.

Table 9 Data on NBI's climate data portal

NBI has precomputed for the entire Nile Basin the relevant climate and hydrological data sets based on downscaled key climate variables from 13 climate models. These include climate datasets on historical climate and future climate projections, that represent the minimum and maximum climate signal change for temperature and precipitation. A report is available that evaluates model performance and signal changes. The data can be obtained from NBI's climate data service portal (Climate Scenario Database | Nile Basin Initiative). The climate data include:

- bias-corrected precipitation and minimum/maximum temperature
- Gridded Intensity Duration Frequency (IDF) matrices
- Probable Maximum Precipitation (PMP)

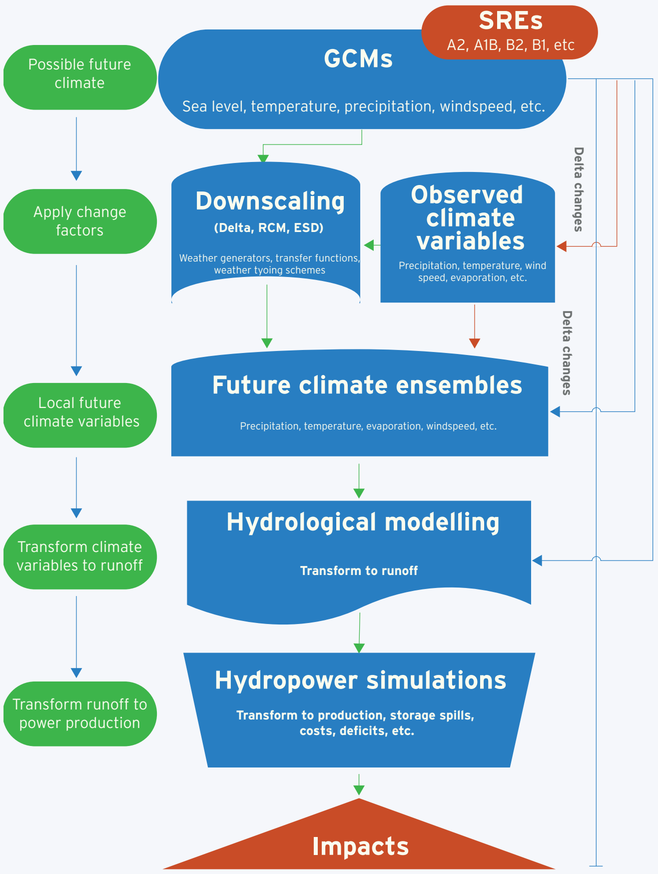
The data are available in 0.44° spatial and daily temporal resolution. The service database portal could be further utilised by Nile countries, where decision makers can carry out climate risk assessments especially with regards to water infrastructure planning. However, remaining differences in availability of historical climate data sets may lead to "gaps" and "holes" in the overall understanding of baseline climate information for some climate parameters regardless of the state of new portals and gridded datasets. When this occurs, it is possible to use proxy datasets and modeled data, particularly for temperature and precipitation related parameters.

Respective indicators can be developed useful for the risk assessment.

Task 4 – Hydrological modelling for simulating the service

Next to assessing structural design performance under climate change, service reliability assessment is an important objective. This involves assessment of effects of climate change on the demand and supply for the infrastructure service. The changes in climate parameters are converted into basic scheme parameters (flow series, flood flows and return periods, evaporation, sediment loads, slope stability etc.). To assess the generation and performance of for example a hydropower project under conditions of climate change, a hydrological model is used to generate future inflows. The flow simulated by hydrological models can be used for service reliability assessments (hydropower, irrigation, etc.) using decision support tools.

Figure 16 Infrastructure service simulation using a hydrological modelling approach (IHA, 2019)



See Figure 16 for the illustration of a flow of coupling models to simulate inflow data, system simulation (hydropower, water supply) data and economic figures. The inflow data from the hydrological model provides the input for the system simulation model which typically includes models that capture reservoir, plant operation, and other parameters such as environmental flow, restrictions and data on demand patterns. An example of such a model is the free nMAG model (Killingtveit, 1999, 2004). Detailed integrated impacts of potential climate change on physical hazards such as geohazard assessment may also be modelled and included. Though, depending on context different approaches towards modelling exist. They are based on the recommendations of the International Hydropower Association which also contains descriptions of some of the methods for hydrological modelling, flood estimation among others (IHA, 2019).

The simulation of the service culminates into a service reliability assessment under climate change conditions. First, the assessment should be done for the baseline and at least one scenario considered representative for the future climate conditions (e.g. centroid of current GCM ensemble such as CMIP6). The sensitivity analysis should be performed covering a possible range of changes in mean annual precipitation and temperature derived from the GCM ensemble. The sensitivity assessment will result in climate response maps or figures showing the performance (economic, targeted service, safety, structural integrity – thresholds identified in Activity 2, task 4) of the project across a wide range of possible climate states.

NBI developed an Excel tool to be used for executing the service reliability assessment based on the hydrological modelling results using the key data products presented in Table 10.

Table 10 Examples of climate data products prepared by NBI

NBI's climate datasets were prepared and organised serving water resource planning taking into consideration climate change. NBI has precomputed the relevant climate and hydrological datasets produced based on the downscaled key climate variables from global climate models for the entire Nile Basin. Intensity, Duration, Frequency (IDF) curves can be obtained from the NBI climate dataset to identify climate change induced changes in rainfall events to be used for hydrological extreme flow analysis and calculating the discharge in a required river catchment. For applying hydrological models, please visit NBI's guidance using Mike-Hydro – Relevant and experienced experts (hydrologists, climatologists, and water resource planners) are needed to carry out this work.

Example of climate data required for assessing service reliability & structural integrity of six projects at pre-feasibility and feasibility stage from the NEL-IP

- Historical precipitation
- Historical daily temperatures
- Historical daily evapotranspiration
- Historical evaporation
- Future daily precipitation
- Future daily temperatures
- Future daily evapotranspiration

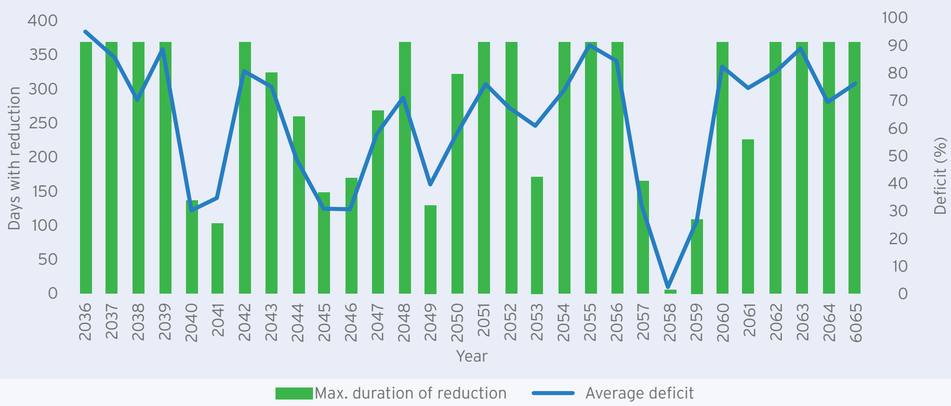
Climate data products required for assessing service reliability & structural integrity of dam infrastructure components (e.g., spillway)

- Historical and future yearly mean flows for assessing service reliability (e.g., hydropower)
- Historical and future Intensity, Duration, Frequency curves (IDFs) for precipitation for developing flood indicators
- Historical and Future Probable Maximum Flood (PMF)
- Historical and Future Probable Maximum Precipitation (PMP)
- Historical and future extreme temperature

As an example, the following graph illustrates a result of simulating future hydro-power performance using the excel tool. Are more detailed description can be accessed at NBI's Integrated Knowledge Portal (IKP) – The Climate Proofing Hub.

The data produced by NBI can be used as input for a rainfall runoff model to simulate the flow in the river.

Figure 17 Hydropower service modelling for future flows using the example of the Angololo Project



Storm profiles need to be considered on top of the IDFs. Storm profiles with a rainfall peak at the end of an event will always produce the worst conditions. The likelihood of such a storm profile needs to be estimated and considered in combination with the selected return period of the rainfall intensity. This is relevant to obtain the overall probability of occurrence of the event. Observed historical timeseries of rainfall in the region can be used to extract storm profiles and determine the prevalent profile for the catchment. After generating different storm profiles, the profiles can be imported to a rainfall runoff model, where they can be used to run the model for the chosen catchment and thereby simulate the flow in the river.

Obtaining the run-off / discharge that forms as a result of these rainfall events can be required for many analyses including the planning and operation of new infrastructures on the river or to facilitate the management of water resources.

Ecosystem Based Adaptation considerations

When EbA interventions are incorporated into simulation modelling, it can require additional effort to establish mathematical or qualitative relationships between key ecosystem components and climate variables, then linking these to changes in overall service provision by the water infrastructure (see the GIZ “Guidebook for Monitoring and Evaluation of Ecosystem-based Adaptation Interventions”). Parameterization of natural systems can be more complex than parameterization of grey/built systems since the former are often associated with greater uncertainty and causal pathways can be poorly defined or may differ across project sites. For this reason, when sensitivity analyses are completed for the hydrologic model, any natural assets that are incorporated may require additional attention to adequately communicate the extent to which uncertainty about parameter assumptions could affect simulated results. Lastly, when using models to evaluate changes in focal service provision under different climate scenarios, EbA-derived co-benefits like new recreation opportunities, biodiversity and habitat, and aesthetic value should also be considered. Including these services may introduce the need to evaluate new trade-offs across focal service provision and co-benefit provision and the nature of these trade-offs may change over time and under future climate scenarios.

Activity 5 – Scoring likelihood and impact, calculating, and evaluating risk

Risk calculation reveals the level of risk that been scored within a stakeholder dialogure process using the data illustrated in the Activity 3. In order to evaluate the data, the results The results obtained are being subject to evaluation whether a risk condition is acceptable or not. Hence, risk evaluation already provides orientation for the signifcance of the risks identified and developing recommendations for resilience.

The objective of this activity is to complete the Risk Assessment using:

- Elements (E) of the infrastructure system defined (services, structural elements, operational elements)
- Exposure (Ex) analysis completed
- Climate Parameters (P) and Likelihood Scores (L) and Impact scores (I) developed
- Risk (R) = Exposure (E) x Impact (I) x Likelihood (L)

Risk Assessment using a Risk Assessment Worksheet

In most PIEVC applications, this work will be recorded on a risk assessment worksheet during a multi stakeholder risk assessment workshop.

Task 1 –Defining the probability / likelihood scoring levels and metrics

The result of the hydrological model from Activity 3, Task 3 provides computed likelihoods by constructing all possible states (e.g., based on different climate ensembles) and constructing probabilities of different thresholds for different climate variables (e.g., probability of occurrence of a flood of a given magnitude), or probabilities of changing return periods by design parameters.

For the risk assessment process, the probabilities are converted to a numeric scale e.g., 1-5. The definition of these probability or likelihood metrics needs to be selected to be as unambiguous as possible. If numerical guides are used to define different probabilities, then units should be given. The probability scale needs to span the range relevant to the study in hand, remembering that the lowest probability must be acceptable for the highest defined impact, otherwise, when it comes to risk evaluation all activities with the highest impacts are defined as intolerable. For water infrastructure the Probable Maximum Flood (PMF) is such as case.

The relevant approaches to estimate likelihood / probability that can be followed individually or jointly are:

- The use of climate data (historical data and projections) and hence be able to compute the probability of occurrence of critical climate events in the future.
- The use of expert opinion that should be draw upon all relevant available information including historical, system-specific, organizational-specific, experimental, design, etc.

Figure 19 Separate scoring scales for baseline and future climate

Level	Likelihood	Expected or actual frequency experienced	Return period (approximate exponential progression; base: power 10^1.3; project with ~100 years' service life)
1	Highly Unlikely	May only occur in exceptional circumstances; simple process; no previous incidence of non-compliance, 0-10% chance of occurring	"Expected to occur on average approximately one time every 500 years"
2	Unlikely	Could occur at some time; 11–25% chance of occurring; non-complex process &/or existence of checks and balances	"Expected to occur on average approximately one time every 150 years"
3	Possible	Might occur at some time; 26–50% chance of occurring; previous audits/reports indicate non-compliance; complex process with extensive checks & balances; impacting factors outside control of organisation	"Expected to occur on average approximately one time every 50 years"
4	Likely	Will probably occur in most circumstances; 51–75% chance of occurring; complex process with some checks & balances; impacting factors outside control of organisation	"Expected to occur on average approximately once every 20 years"
5	Almost certain	Can be expected to occur in most circumstances; more than 76% chance of occurring; complex process with minimal checks & balances; impacting factors outside control of organisation	"Expected to occur on average approximately once every 10 years"

Task 2 – Score the likelihood climate change

System elements	Climate parameters / hazards						
	Climate parameter A				Climate paramete		
	Indicator				Indicator		
	L score =			2	L score =		
	Ex	L	I	R	Ex	L	I
Structures							
Dam							
Elements x, y, z	1	2			0		
Hydropower							
Elements x, y, z	0				1	4	
Operations							
Elements x, y, z	1	2			1	4	
Services							
Elements x, y, z	1	2			0		

The scoring of likelihood is a process of translating the scientific findings of current and future climate into a score that is applicable to be used for calculating and evaluating overall risk.

In some cases, to avoid biasing the scoring process with a conflation between changes in likelihood and impact, it is appropriate to withhold climate likelihood scores until the impact scoring is complete. Whether the two processes are completed separately before joining the results is a decision to be made by the project team.

There are some key considerations for the likelihood scoring process that should be factored into each analysis. These key considerations are:

- Scoring is an iterative process, where hazard indicator definitions (based on impact thresholds) and likelihood scores are developed by the climate specialist and reviewed with the project team. Time for revisions and consultation should be considered in the risk assessment process.
- Hazards should not only include historically occurring hazards, but ones that could potentially manifest under future climate change. For example, if a region has never experienced maximum temperatures over 40°C historically but could within the assessment time horizons, this hazard should be included in analysis.
- Some hazards may require multiple indicators/thresholds as impact (surpassing thresholds) is not always proportional to event likelihood of occurrence.
- Estimates of likelihood are sometimes based on climate parameters that are not perfect matches for the ones of interest by the project team. This is possible as likelihood scores represent a wide range of likelihoods within each “bin”.

The example below illustrates examples of likelihood scores for different climate indicators developed and different time scales of projections. The likelihood scores are then transferred into the risk matrix.

Table 10 Examples of likelihood scoring for different climate indicators and elements under assessment

Climate parameter	Index name	Index description	Recent past (1981-2010) estimated value	Present probability score	2050s (2041-2070) estimated value	2050s Probability Score	2080s (2071-2100) estimated value	2080s Probability score	Probability score definition method	Trend	Direction confidence	Magnitude confidence
Temperature	Annual average temperature (TMm)	The average temperature across all months of the year	13.5 °C	3	16.2 °C	4	18.6 °C	5	C	↑	High	High
	Very hot days (+35 °C) (TXge35)	Days when maximum temperature is >= 35 °C	0.1 days	2	7.1 days	3	22.8 days	4	B	↑	High	Medium
	Very hot days (+30 °C) (TXge30)	Days when maximum temperature is >= 30 °C	8.3 days	2	44.0 days	3	86.0 days	4	B	↑	High	Medium
	Heat wave (TX90p)	Amount of hot days (i.e. percentage of days when maximum temperature is >90th percentile)	10%	3	38%	4	58%	5	B	↑	High	Medium
	High temperature (TXx)	Warmest daily maximum temperature	32.4 °C	3	36.1 °C	4	38.9 °C	5	C	↑	High	Medium
	Heating Degree Days (HDD)	Heating degree days are equal to the number of Degree Celsius a given day's mean temperature is < 18 °C	1781 days	3	1116 days	2	707 days	1	B	↓	High	Medium
Precipitation	Number of very heavy precipitation days	Number of days when daily total precipitation >=20 mm	3.8 days	3	4.9 days	4	5.5 days	5	C	↑	High	Medium
	Extremely wet days (R99p)	Annual sum of daily precipitation >99th percentile	40.3 days	3	60.4 days	4	75.3 days	5	C	↑	High	Low
	Five-day maximum (Rx5day)	This describes the largest total amount of rain that falls over a period of 5 consecutive days in a year	71 mm	3	77 mm	4	80 mm	4	C	↑	High	Medium
	100 year – 24 hour duration	Design precipitation	63 mm	3	65 mm	4	68 mm	5	C	↑	High	Low
	200 year – 24 hour duration		68 mm	3	69 mm	4	73 mm	5	C	↑	High	Low
	Regional Maximum Precipitation (RMP)		More Analysis Needed									
	Safety Evaluation Precipitation (SEP)		More Analysis Needed									
	Probable Maximum Precipitation (PMP)		More Analysis Needed									
Wildfire	Consecutive Dry Days (CDD)	Maximum number of consecutive dry days (when precipitation <1.0 mm)	49.7 days	2	57.2 days	3	62.5 days	4	C	↑	High	Medium
Evapo-transpiration	Standardised Precipitation Evapotranspiration Index	Characterization of wet/dry periods over a 24-months timescale	0.002	2	-1.36	3	-2.84	5	C	↑	High	Medium
Wind	50-year (@ 10m) return level of annual maximum wind speed	This describes the 50-year return level of annual maximum wind speed. That is, wind speed that has a 1-in-50 (2%) chance of being met/exceeded per year	9.3 m/s	2	9 m/s	3	8.9 m/s	3	C	↑	Medium	Low
	Wind direction as a rosette	Graphical representation of speed and direction of winds at a location	south easterly	0	south easterly	0	south easterly	0	C	·		Low
Lightning	Average number of strikes per year in grid relevant to watershed	Average number of strikes per year	10 flashes km²/year	2	12 flashes km²/year	3	15 flashes km²/year	4	C	↑	Low	Low
Solar radiation	Average annual daily radiance	Power density in units of kW/m²	Unknown	1	increasing	2	increasing	2	C	↑	Low	Low

An example of how likelihood is scored for historical and future discharge is presented in Box 7.

Box 7 Averaging likelihood and translation into likelihood scores

historical			RCP 8.5 future	
1971-2000 Year	Likelihood of Occurence [-]		2036-2065 Year	Likelihood of Occurence [-]
1971	1		2036	1
1972	1		2037	1
1973	1		2038	1
1974	1		2039	1
1975	1		2040	0
1976	0		2041	0
1977	0		2042	1
1978	1		2043	1
1979	1		2044	0
1980	0		2045	0
1981	1		2046	0
1982	1		2047	0
1983	0		2048	1
1984	1		2049	0
1985	1		2050	0
1986	0		2051	1
1987	0		2052	1
1988	0		2053	0
1989	1		2054	1
1990	1		2055	1
1991	0		2056	1
1992	0		2057	0
1993	0		2058	0
1994	0		2059	0
1995	1		2060	1
1996	1		2061	0
1997	1		2062	1
1998	1		2063	1
1999	1		2064	1
2000	1		2065	1
Sum	19,00		Sum	17,00
Probability	63%		Probability	57%

Preferably the expert will be able to simulate as many years as possible. The projected discharge from the hydrological model can be used to derive the occurrence of impactful events with a certain severity score level defined in Activity 2, Task 3 and 4. Depending on the number of simulated years and the number of occurred events, the likelihood of occurrence can be calculated in percentage and applied to the scoring system.

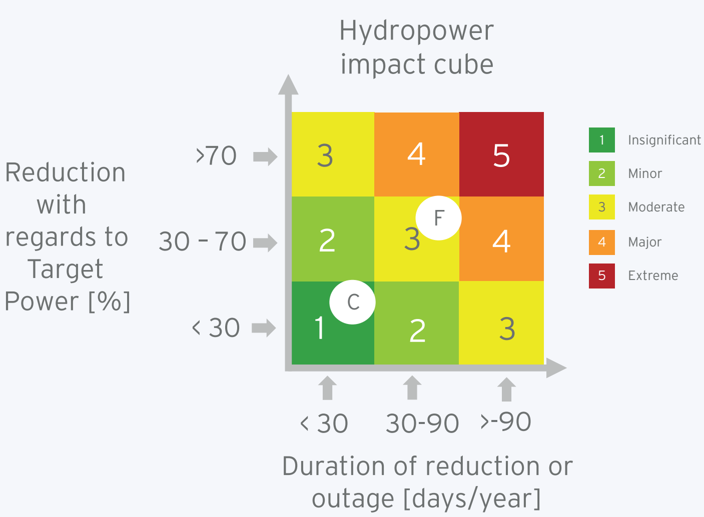
Task 3 – Score the impact severity

System elements	Climate parameters / hazards							
	Climate parameter A				Climate parameter B			
	Indicator				Indicator			
	L score =			2	L score =			4
	Ex	L	I	R	Ex	L	I	R
Structures								
Dam								
Elements x, y, z	1	2	4		0			
Hydropower								
Elements x, y, z	0				1	4	5	
Operations								
Elements x, y, z	1	2	3		1	4	1	
Services								
Elements x, y, z	1	2	1		0			

For each interaction between an infrastructure element and a climate event type score the Impact Severity based on the scoring system developed (see example from Table 3). Often the impact severity scored is built upon a substantive and controversial discussion amongst stakeholders. When consensus has been built a thorough documentation of the arguments put forward for having arrived at a specific score is necessary.

Documentation of the selected impact scores for each element will assist in understanding the risk scores as well as assist in developing recommendations later in the assessment. Comments may describe effects, measurable outcomes (e.g., how it affects the operational goal, duration of outage, safety, critical infrastructure loss, financial, environmental effect, reputation, etc.). Organizations may choose other scales based on their project objectives. It is important the results of the scoring of severity of impact need to be reasoned well, if not even scientifically grounded. Once, in a stakeholder workshop the impact severity is scored the accompanying discussion needs to be well documented to ensure collective liability for the final risk scores developed.

Figure 20 Impact severity scoring example on current climate (c) and future climate (f)



Finally, the impact severity scores are transferred to the risk matrix.

Task 4 – Calculate Risk Score

Calculate the Risk (R) for each interaction Risk (R) = Exposure (E) x Impact (I) x Likelihood (L), where (E) is either yes=1 or No=0

The results are documented in the risk matrix. Now the risk matrix is completed.

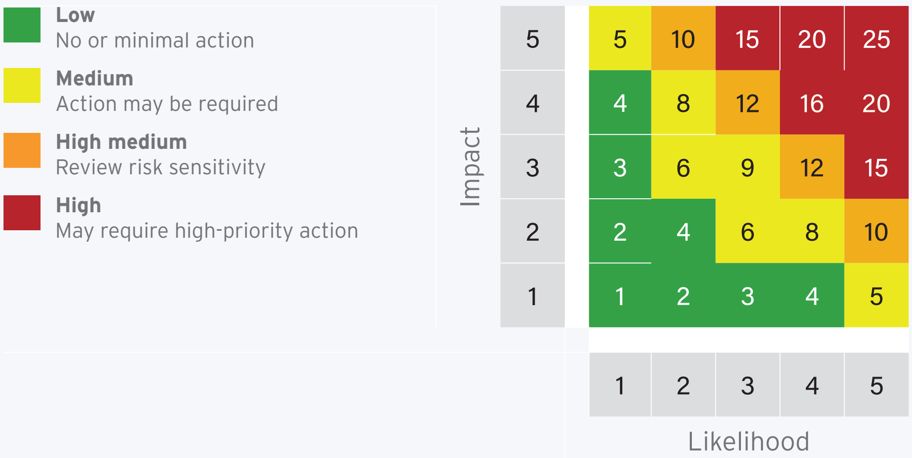
Table 11 Example matrix of the PIEVC methodology for the Borenga dam a single asset type of risk assessment (components were more than in this shortened representation)

	Climate parameters / hazards							
System elements	Climate parameter A				Climate parameter B			
	Indicator				Indicator			
	L score =			2	L score =			4
	Ex	L	I	R	Ex	L	I	R
Structures								
Dam								
Elements x, y, z	1	2	4	**8**	0			
Hydropower								
Elements x, y, z	0				1	4	5	**20**
Operations								
Elements x, y, z	1	2	3	**6**	1	4	1	**4**
Services								
Elements x, y, z	1	2	1	**2**	0			

Task 5 – Evaluate the Risks for risk tolerance

Summarise and classify risk using the scales provided. Assessors may adjust the classification categories as appropriate to align with the infrastructure owner's risk appetite. The resulting risk calculation shows whether a given risk is high, medium, low. This involves establishing the risk levels based on probabilities of occurrence of a given undesirable event and the impacts experienced should such an event occur. This also includes the assessment of the widest possible range of potential impacts, including low-probability outcomes with large impacts. The risk levels assigned to the cells will depend on the definitions for the probability/impact scales. These can be defined by the stakeholders.

Figure 21 Heat map with risk tolerance thresholds



Stakeholders will determine the level of risk they are willing to bare. This level of risk may be linked to key project thresholds which should not be exceeded. Some of these may be technical and economic/financial thresholds relating to infrastructure in addition to other socio-economic and environmental criteria. The project objectives and excepted performance metrics should already provide a good basis for establishing the necessary thresholds. The level of risk would inform whether further study is required to manage the risk.

Task 6 – Prioritise risks based on the risk evaluation

- Discuss the evaluated risk
  - Consider other factors that may be used to classify risk into priorities.
  - Consider timing, cost, available resources, finance, legal, O&M, risk tolerance, etc.
- Identify and discuss special case risks
  - Low Likelihood – High Impact that could represent significant concerns, despite low risk assessment scores.
  - High Likelihood – Low Impact that could represent significant concerns, despite low risk assessment scores.
- Based on the prioritization, identify:
  - Interactions that require no action currently (Low Risk).
  - Interactions that may require further attention, study over time (Medium Risk).
  - Interactions that require immediate action (High Risk).
  - Special case risks.
- Prepare a Concluding Statement that identifies:
  - The overall level of confidence in the assessment based on the level of detail.
  - Context regarding the level of assessment and application of findings.
  - The amount of vulnerability or resiliency of the system.

- The global limitations of the assessment.
- The time horizon of the assessment.
- Climate trends that contribute to the vulnerability of the system.

Activity 6 – Recommendations and reporting

Drafting recommendations as a starting point of risk treatment is essential, as they are revealed directly from the risk assessment process. The risk assessment team is finalizing its task by developing a joint report that is documenting all relevant findings related to stated and evaluated risks, data sufficiency and the recommendations provided.

Task 1 – Develop recommendations for next steps, risk treatment and data sufficiency

- Develop recommendations for identified risks.
  - Provide justification for each recommendation.
  - Incorporate, as much as possible, organization risk tolerance and acceptable residual risk.
- Categorise the recommendations according to for example:
  - Policy/procedural changes.
  - Remedial actions.
  - Further study or analysis.
  - More comprehensive risk assessment (e.g., using the full PIEVC Protocol).
  - Engineering design considerations to engineering analysis, preliminary
  - design criteria or design changes.
  - Risk avoidance strategies.
  - Consider stopping activities in high-risk areas.
  - Other, as appropriate.
- Discuss next steps and the frequency and nature of monitoring and review of risks.

Task 2 – Develop a report on the risk assessment, evaluation and recommendations

- Prepare a Statement of Assumptions and Limitations
- What was and was not considered?
- Which timeframes were considered?
- Which RCPs or future scenarios were used?
- Comment on missing, unavailable data and uncertainty.
- Comment on steps taken to address missing or unavailable data.

Step 3: Risk treatment

Risk treatment aims at managing the climate risks that may impact the ability of programs and projects to achieve their objectives. The project must be able to cope with the significant potential changes due to climate change that are assessed.

For example, the structural design and hydraulic designs must be sufficient to cope with climate change but also not be so expensive that the objectives of the project cannot be achieved (i.e., adopt a minimum regret alternatives). Specific Risk Management actions within the project (structural and/or non-structural) will be made or documented. Each modified design will include one or a combination of the resilience (functional and/or structural) measures. The set of modified designs can range from one with minimal changes to one with more significant adjustments. In some cases, these modified project designs can be identified using expert judgment. In other cases, robust technical-optimization methods can be used to select promising combinations of options. The range of modifications practically available will be larger for new projects or those under major rehabilitation or expansion than for operating projects.

The process of identifying the best suitable resilience measures may be an iterative process to test the measures (if not already defined in the project) for addressing all risks in the management plan. Iteration means conducting one or more stress tests (CCRA) to test the robustness of the mitigation measures or to document the comparative economic indicators of choosing between different adaptation strategies. This includes assessments for any changes in the natural hazards risk as already identified by existing project studies.

The process of risk treatment to arrive at viable, effective, and feasible risk treatment options within a climate proofing approach is simplified as the following:

Activity 1 – Identifying risk management options

This step is often carried out as a last step of risk assessment where recommendations are being developed and carried over to a thorough risk treatment process. When identifying options, no constraints or criteria are usually applied to allow for the most creative exercise that enhances innovative thinking.

Activity 2 – Assessing and selecting different risk management options

Typically, all risk treatment options have social, environmental, economic, institutional, physical, and operational implications and need to be selected carefully utilizing different methodologies, such as cost-effectiveness, cost-benefit analysis: Understanding the benefits and trade-offs, as well as cost-benefits of alternative risk management actions is important. The complexity of adaptation actions across scales and contexts means that monitoring and learning are important components of effective adaptation. The process is iterative and can take several rounds before the mitigation and adaptation options are defined.

The strategy for the different types of projects is as follows:

- Existing projects: assess whether simple structural and functional measures can be implemented to current components and operations.
- Planned projects: identify the design that is the best feasible that balances meeting performance metrics with the potential for future modification. Perform incremental cost-benefit analyses on key project components that are being optimised.
- Future projects: assess design options that can be cost-effectively built to be flexible and that can be modified for different climate scenarios following an adaptative approach (e.g., increased storage, different sites for new projects).

It is necessary to evaluate the ability of each adaptation option/proofing measure to reduce the potential risks while satisfying the specified performance metrics for the future climate scenarios.

- Re-run the design options through the models to undertake the climate stress test in the same way as previously done.
- Determine the most resilient project design using the results from the evaluation of the options
- Calculate the potential loss (regret) of each modified project design in each scenario. The potential loss (or regret) of a design in any scenario is the difference between the performance of that design in that scenario and the performance of the best design for that scenario. Note that each design will have a separate value of regret for each performance measure.
- Identify project design with the minimum maximum loss (regret): Identify the maximum regret for each project design alternative. The project with the minimum maximum regret is the most climate resilient design among the options

- Identify tolerable loss: Each performance measure may have a tolerable level of regret identified and agreed with key stakeholders. The design for which the regret is within this tolerable level of regret for the greatest number of scenarios is the most robust strategy.

Evaluate results and act: If the results suggest a similar design, then that project design option is chosen as the resilient design. Otherwise, identify additional options to bring the project options to within the tolerable loss. IHA, (2019) has an example for regret calculation that can be adopted. The example shows NPV.

Figure 22 Example for calculation of regrets between two designs

The desire is to maximise NPV

1. Minimising the maximum regret criterion

- A performs best in scenario 2 and 3
- A performs worst in scenario 1
  with a maximum regret of 6 compared to B
- **Select Design B**

2. Satisfactory regret criterion max(regret) S 3 OK for owner

- Design B still the most resilient as the difference in regret never goes above 3 across scenarios

3. Satisfactory regret criterion max(regret)S 2 OK for owner

- Neither design meets criteria for resilience as all max(regret)›2
- **Seek scenario C**

NPV of the project options

	Climate Scenario		
	1	2	3
Design A	4	10	5
Design B	10	7	4

Regrets between the project Options

	Climate Scenario		
	1	2	3
Design A	6	0	0
Design B	0	3	1

If the evaluation does not eventually identify a resilient design the project design can either be:

1. Further adjusted, if there is an individual feature that has been shown to not meet the resilience requirements (e.g., a dam can be redesigned to accept overtopping without failure for extreme floods). A new climate stress test has to be carried out.
2. The project may be completely reformulated or redesigned, if the overall project or components of the project fail to meet the resilience. May require restarting the process or taking another alternative.
3. The project may be abandoned if it is deemed too risky.

Activity 3 – Implementation of selected risk treatment options

Once a project's mitigation and adaptation options are selected, they must be mainstreamed into policies, feasibility and design studies, infrastructure safety plans, retrofitting procedures, depending on the context of climate proofing. Given that climate change trends have a high uncertainty, monitoring must be implemented during the project operation phases.

Step 4: Monitoring and evaluation

Developing and implementing an adaptation-focused monitoring and evaluation (M&E) system is key to measure if and how infrastructure investment projects are performing regarding managing climate-related risk. It is a permanent learning process, useful to replicate successful and avoid unsuccessful lessons learnt in the future.

Often, M&E is used for transparency and requested from investors, being a mandatory exercise to account for used resources. Thereby, the objective is to monitor the effectiveness of the mitigation and adaptation measures and eventually carry out new risk assessments and risk treatment.

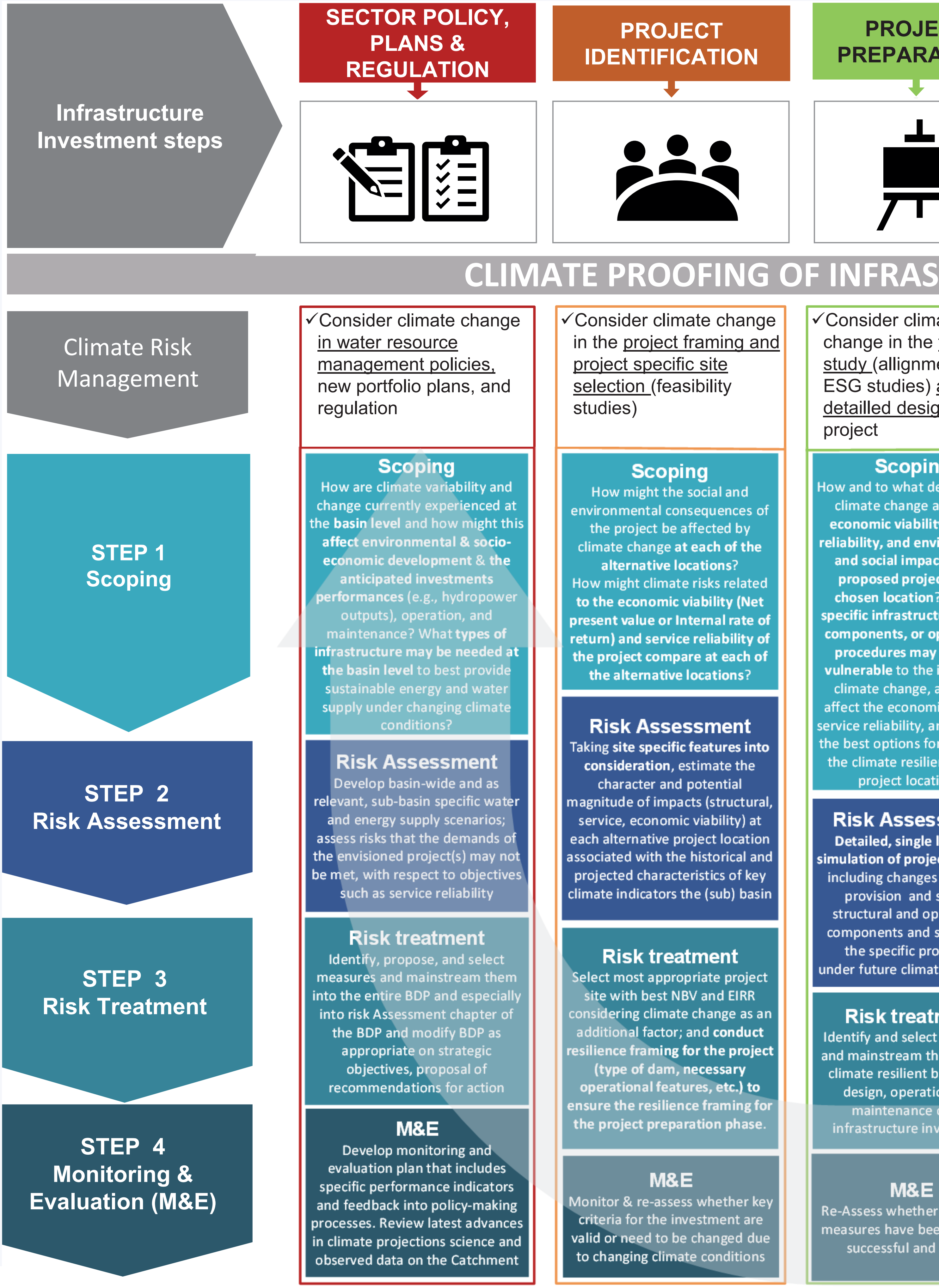
Infrastructure investment projects vary regarding the individual project, contexts, locations, and scales. Therefore, no universal indicators exist, and success cannot be measured with one indicator only. As such, the establishment of a baseline is crucial to create a reference point, pursuing to measure impact. This baseline can often be a climate risk assessment. M&E systems in the context of adaptation to climate change can be designed focusing on a variety of metrics. Commonly, measuring variables can be climate parameters, climate change impacts, vulnerability, implementation of adaptation measures, or the impact of adaptation measures. All these foci are valid; however, they do not always necessarily contribute to measuring relevant variables in the context of infrastructure investment.

4 CLIMATE PROOFING AND PROJECT CYCLE MANAGEMENT

For climate change adaptation to be sustainable, it must be incorporated, integrated or "mainstreamed" into the policy apparatus of governments, into business development and practices. This means incorporating climate risk considerations into every aspect of the policy and project development process and decisions by government, communities and private sector (Bockel, 2009; Amuzu et al., 2018).

NBI's climate proofing approach is about mainstreaming climate risk management into all stages of the upstream and downstream infrastructure planning and investment decision making process. Hence, the NB riparian countries' frameworks for investment planning or NBI's specific approaches towards transboundary planning and project development define the nature and methodological approaches towards climate proofing. Hence, each chapter of this step-by-step guidance has a unique approach towards climate proofing, including different scope, types of risk assessment and treatment to be carried out.

Figure 23 NBI's climate proofing approach



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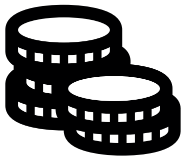
RESOURCE MOBILIZATION



✓Consider climate change in decisions on costings and insurance schemes

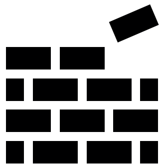
Scoping
How might projected climate change **affect the estimated costs and benefits of the project?** If there are multiple technically feasible and economically desirable climate-proofing measures provided at project preparation stage, which of these should be recommended and why? Should the co-benefits associated with certain climate-proofing measures, such as ecosystem-based approaches, be included in the economic analysis?

Risk Assessment
Based on prior findings assess in greater depth and the financial and economic project performance of the project, under the full range of adopted climate change scenarios and adaptation options investigated in project preparation phase

Risk treatment
Engagement with Insurances providers and potential donors and banks and demonstrate the project's climate resilience and risks of monetary loss.

M&E
Re-Assess whether policies contracted cover current & future climate risks

CONSTRUCTION



✓Consider climate change in the operational procedures of dam construction (construction period can take several years)

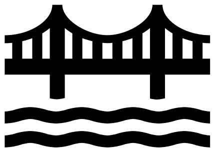
Scoping
Could any temporary, **construction-related infrastructure be at risk because of climate variability or change, extreme weather?** Have there been any **consequential advancements in the understanding of climate change and related risks in the region, during the construction phase of the project**, that can be taken into consideration?

Risk Assessment
Further analysis of critical project design thresholds most sensitive to climate, especially if relevant new findings have become available regarding the impacts of climate change for infrastructure assets that support the construction and may not yet have been assessed.

Risk treatment
Establish warning and response systems as well as options to protection of assets and people in case of climate related extreme events.
Approaches to mitigating runoff from and sedimentation because of cleared ground may require different climate analyses than what would have been conducted to inform project design and, later, operations. In such cases, the new designs may have to be checked for their resilience using the approach defined under the project preparation stage.

M&E
Re-Assess performance of these SOPs and adaptation measures during construction.

OPERATION & MAINTENANCE, RETROFITTING



✓Consider climate change in operational procedures and maintenance schemes (adjustments to maintain reliable services of the infrastructure

Scoping
Is the **performance of operating infrastructure potentially at risk** due to changes in the climate-related hazards **that do not conform to design- or operations and maintenance-related assumptions?**

Risk Assessment
Monitoring of changing climate-related risks over time, whether because of changes in the infrastructure or its operating environment and their interactions with the changing climate. Moreover, identification, assessment, and evaluation of new risks associated with the changing climate.

Risk treatment
In case changes in risks are identified, identification and selection of measures to increase the resilience of the physical and operational components of the infrastructure and updating and implementing a climate resilient dam safety management plan.

Monitoring & Evaluation
In case changes in risks are identified, provide feedback into the entire investment cycle where appropriate. Regular monitoring should be undertaken of the environment and adaptation measures to ensure that they are providing the expected level of risk reduction.

TRUCTURE INVESTMENTS

NBI's climate proofing approach is about mainstreaming climate risk management into all stages of the upstream and downstream infrastructure planning and investment decision making process of the NBI. Hence, the NB riparian countries' frameworks for investment planning or NBI's specific approaches towards transboundary planning project development cycle define the nature and methodological approaches towards climate proofing.

Climate proofing should be done from the early stages of the project likewise social and environment studies are done parallel to other engineering and technical activities. At each stage of the project cycle, adaptation alternatives must be evaluated. The process should culminate in the choice of the alternative(s) with the least regrets. The chosen project configuration with the least regrets is the one that should be subjected to further development stages and the corresponding climate proofing activities

Hence, as the project development progresses, each of the steps have different objectives and approaches towards climate proofing. This provides a platform for enabling the evolution of the level of details in the analyses as the project development progresses. In the beginning of a project, there will usually be less information about some detailed aspects of the project than at later stages. As such, the climate proofing should have different scopes of work at the different stages.

The level of detail (data, assessment methods and project characteristics) is less rigorous for the initial stages in the project cycle than for the later stages because the information about the design, and climate change impacts will usually have less detail at the beginning of the project cycle than at later stages.

With this approach Climate Proofing may be done for new projects or / and for existing projects/infrastructure in operation.

- For **new and existing projects**, the entry point for climate proofing can be at the policy, planning and regulation stage. Whether existing infrastructure portfolios need to be retrofitted or new directions of water resource management need to be established is dealt with at this level.

- For **new projects**, the entry point for climate proofing can be at policy and planning stage, but can also start with the identification, or preparation stage.

- For **existing projects** that are in operation and have not been subjected to climate proofing processes yet, the entry point is mainstreaming climate into retrofitting / refurbishment, dam safety plans, and maintenance schemes of the operating project. As a detailed design is already in place and the climate impact assessment can therefore be targeted to the performance of project components that are vulnerable to climate change. Additional funding might be requested upon laying open the climate risks.

For each stage in the project cycle, the accomplishment of the five generic climate proofing is necessary. These activities are repeated at each project phase with varying details and objectives. Detailed descriptions of the climate proofing steps and activities are presented in following sub-chapters. Some of the descriptions are based on experience from existing reviewed guidelines such as NELSAP, 2012; Eickhof, Centre and January 2014; ADB, 2016; Asian Development Bank, 2017; World Bank, 2017; IHA, 2019.

4.1 Climate proofing at the level of policy and planning

When developing strategic plans, asset management plans, catchment or transboundary management plans, infrastructure master plans as well as respective sector policies and regulation for infrastructure investments, the overall framework conditions for investments are determined. For example, trans-boundary cooperation in hydropower development and management would enable Nile riparian countries unlock and optimise the hydropower potential and allow for a more efficient location and operation of hydropower infrastructure.

In the context of NBI's mandate to strengthen transboundary IWRM, this means focussing on the Nile Basin as a whole, its basins and catchments and develop integrated water resource management policies, plans, and regulation. The benefits of a basin approach to water resource management are to allow the sharing of the costs and benefits of water infrastructure investments, to ensure their optimal location in a river basin and to prevent possible negative effects of uncoordinated or conflicting investment measures into water infrastructure for individual projects in the river basin.

Taking a few policies, planning and regulation schemes as examples the need to incorporate climate resilience therein is explained in greater detail.

1. **Consider climate change in strategic planning (national level or transboundary level)**

A strategic plan is an overarching planning document that outlines goals and objectives for a collection of projects. A strategy/strategic plan should provide realistic guidance to effectively allocate municipal resources (human, physical, and financial). Strategic Plans outline what a municipality wants to achieve, but not necessary how to achieve it.

Incorporating climate change projections and future scenarios can help a municipality better budget resources to align with future needs. Planning for the future using historical practices and data no longer provides an accurate picture of the future. Climate projects can provide an understanding of a likely future, or likely scenarios that a municipality will need to operate within.

2. **Consider climate change in regional / transboundary plans**

Regional plans outline matters that impact multiple jurisdictions or municipalities. These plans document big-picture solutions to issues that cross town or city boundaries, such as environmental, social, and economic issues. Regional plans outline a collaborative approach to planning, and aim to address factors such as population growth, urban sprawl, maintaining farmland, planning efficient transportation networks, and protecting natural areas.

Incorporating climate change considerations into regional planning can encourage a cross boundary approach that works towards the same goals, initiatives, and actions. Incorporating climate change resiliency into all components of the plans, i.e., planning for hydro power, water supply and irrigation using additional mechanisms such as dam cascade management, or procurement of goods and services and municipal tools such as zoning by-laws and land use planning that considers climate vulnerable areas.

3. **Consider climate change in asset management plans**

Asset management plans are used by infrastructure owners to manage their entire portfolio of infrastructure and other assets to deliver an agreed standard of service. These plans can help infrastructure owners make effective planning decisions about building, operating, maintaining, renewing, and replacing infrastructure across multiple time horizons.

Climate change can be integrated in asset management plans by considering how climate hazards (such as extreme temperature, high winds, rainfall, etc.), may impact an portfolio of assets, and by understanding how those interactions and impacts are expected to change over time. Undertaking a risk assessment of existing assets in your municipality will allow you identify potential hazards of importance, likelihood of occurrence, asset vulnerabilities, and impacts of climate change. High risk assets can be identified and prioritised, and asset management strategies can be assigned, as well as the appropriate resources (human, physical and financial), required to maintain established levels of service.

4. **Consider climate change in master plans and supporting plans**

Infrastructure plans identify infrastructure improvements required to maintain levels of service, often planning for a 30-year time horizon.

Incorporating future climate protections into the planning process is critical, as historical trends no longer adequately reflect current and future norms. Undertaking initiatives to document how climate change will likely impact infrastructure assets and systems and determining how those impacts will influence level of service is a critical step in understanding how to plan for resilient infrastructure

5. **Consider climate change in regulative policies and tools**

- **Procurement**: Procurement is the process of finding and agreeing to terms and acquiring goods and services, or works from an external source, and can be rendered through tendering or a competitive bidding process. Many municipalities have begun to think about and implement sustainable procurement initiatives. Sustainable and resilient procurement can help a municipality achieve its goals and better prepare for climate change. I.e., procuring climate resilient or appropriate construction materials that can better withstanding a changing climate and extreme weather events. Investing in climate resilient products and services can deliver value over the long-term.

- **Tools**: Municipalities can use a variety of tools to address policies. Tools include regulatory tools, such as resilient infrastructure guidelines, design guidelines, permitting, resiliency standards and zoning bylaws, etc. Municipal tools can incorporate climate risk, vulnerability, and adaptation by setting directions for regulation that take into consideration municipal climate projections, risks, and vulnerabilities. For example, zoning and land use bylaws such as through zoning bylaws that evaluate, and prioritise/avoid land based on climate change risks or minimise vulnerability through land use designations.

Step 1 – Scoping - Relationship to climate proofing

Climate change and variability add to the definition, characterization, and prioritization of transboundary issues in the basin, and of the environmental and socio-economic impacts of development more generally.

Climate fundamentally affects water supply in river basins and sub-catchments. River basin plans must therefore incorporate climate change considerations to help ensure the most viable mix and types of infrastructure (grey and natural) are proposed for furnishing sustainable supplies of energy and water.

Key questions

1. How are climate variability and change currently experienced at the basin level, how might this evolve over future time periods, and how could this affect the environmental and socioeconomic impacts of development?

2. How might hydroclimatic conditions, including extreme weather-related events such as droughts, floods, storms, and landslides affect the project's location(s), performance (e.g., hydropower outputs), operation, and maintenance?

3. What types of infrastructure may be needed at the basin level to best provide sustainable energy and water supply under changing climate conditions?

4. How do current investment policies, plans, and regulations affect the risk of climate change impacts on physical structures and natural assets in the basin, and the services they provide?

5. How have existing projects of the proposed type been affected by climate variability and change in the region, and how has this affected the services they provide?

Key outputs

Climate Proofed Basin Development Plan that explicitly describes how investment proposals have considered climate change.

Ecosystem Based Adaptation considerations

During the sector policy and planning stage, if Ecosystem based Adaptation is to be included in a water infrastructure project as a climate-proofing measure, it is important to consider the implications for spatial, temporal, participatory, and jurisdictional scope. For example, it may be desirable to extend a project's spatial boundaries to include a wetland that provides water filtration or flood attenuation services downstream. If the supply of those services is only seasonal it may introduce new temporal considerations into the decision-making context. Extending the spatial boundaries may also mean the project now overlaps with the lands and interests of new groups such as private landowners, other domestic administrative jurisdictions, other countries, and/or Indigenous groups with unique rights (World Bank 2017). When this is true, it will increase the number of affected parties that should be engaged in the planning of investments prior to identifying and selecting project alternatives for evaluation.

Special Considerations for Ecosystem-based Adaptation When Evaluating the **Problem Definition and Objective Setting:**

Including EbA can expand the spatial, participatory, and jurisdictional scope of a water infrastructure project when the project boundary is extended to include natural assets (e.g., a wetland) that may exist in other jurisdictions but provide benefits to water infrastructure downstream.

A high-level climate risk assessment that incorporates the IPCC's exposure, adaptive capacity, and sensitivity elements can inform the identification of EbA options by highlighting key components of the natural environment like wetlands and floodplains that are exposed to climate hazards and that can be harnessed to increase adaptive capacity.

The availability of EbA alternatives can influence objective setting by introducing additional co-benefits beyond focal service provision of water infrastructure.

Step 2 – Risk Assessment

Main Objectives

1. Provide an initial assessment of risks related to the observed and future impacts of key climate conditions on water supply and demand, energy production, and other socioeconomic, transboundary, and environmental issues basin wide.

2. Identify potential implications for alternative project locations and types and provide accompanying rationales based on the initial basin-wide climate risk assessment.

Approach

Focus the assessment on those climate conditions and related variables that most significantly impact annual and seasonal water and energy supply and demand basin wide. Identify more specific impacts and risks – e.g., at the sub-basin or specific alternative project level – only if information of greater resolution or technical detail could fundamentally affect the identification of potential alternative project locations or types of projects. Use existing studies, indicator-based approaches, expert judgement, and, as relevant, the results of prior dynamic (e.g., hydrological) modelling efforts, to assess impacts, risks, and opportunities.

Characterization of basin-wide climate risk

1. Define the boundaries and main physiographic components of the basin together with the climate conditions that most influence basin hydrology, related environmental conditions, and management issues.

2. For each identified climate condition, define a variable (e.g., mean summer precipitation) and characterise its historical and future trends, variability, and extremes by using historical data and GCM and/or RCM (Global and Regional Climate Model) projections for the basin (and sub-basin where relevant), for the most recent Normal period and the near and far future (30 years, 60 years, etc.), respectively. These Essential Hydroclimate Variables (EHCVs) should be selected based on their direct relevance for water management and use in the basin. New EHCVs may be added, and existing EHCVs adjusted, during later steps of the project investment cycle; as prospective project locations and designs are narrowed down, and more detailed climate impact and risk assessments are conducted. Projections should be provided for at least the highest greenhouse gas emissions scenario, using an ensemble of climate models. In some cases, EHCVs may be aligned/combined with known thresholds of impact for the function or condition of natural or built assets in the basin, for use as climate hazard indices.

3. Estimate the character and potential magnitude of impacts – on the defined socioeconomic, transboundary, and environmental issues – associated with the historical and projected future basin-wide EHCVs and, where relevant, EHCVs at the sub-basin level.

Risk screening of anticipated investment projects

1. Identify and characterise past climate-related impacts on projects comparable to those specified in the Plan, considering physiography, bio-geoclimatic zone, design constraints, service requirements, and/or other factors of potential impact.

2. Using outputs of the analyses above, develop basin-wide and as relevant, sub-basin specific water and energy supply scenarios; assess risks that the demands of the envisioned project(s) may not be met, with respect to objectives such as service reliability, Net present value (NPV), or Internal rate of return (EIRR).

3. Rank risks using a defined scale.

Hydroclimate data requirements

1. Use basin development maps and digital terrain models to determine projects' potential exposure to specific climate-related hazards (e.g., landslides).

2. Use climate and hydrological observations and projections for time periods of at least 30 years, for the identified EHCVs. In the absence of future hydrological projections (e.g., streamflow), climate proxies (e.g., precipitation extremes as proxy for flooding) can be used.

3. For the projections, use available global or regional (GCM/RCM-based) climate scenarios, statistically downscaled where possible.

4. Based on the EHVCs, begin to identify climate thresholds – drawn from known inflection points in the condition, or structural or functional performance of key built or natural assets in the basin, or in other comparable settings; establish climate (hazard) indices and compute related statistics (e.g., likelihoods of exceedance) based on these indices.

Step 3 – Risk Treatment

1. Define how climate change needs to be considered for the Catchment Planning Process

2. Use the results and mainstream them into the Basin Development planning process and other relevant investment planning processes at the national level.

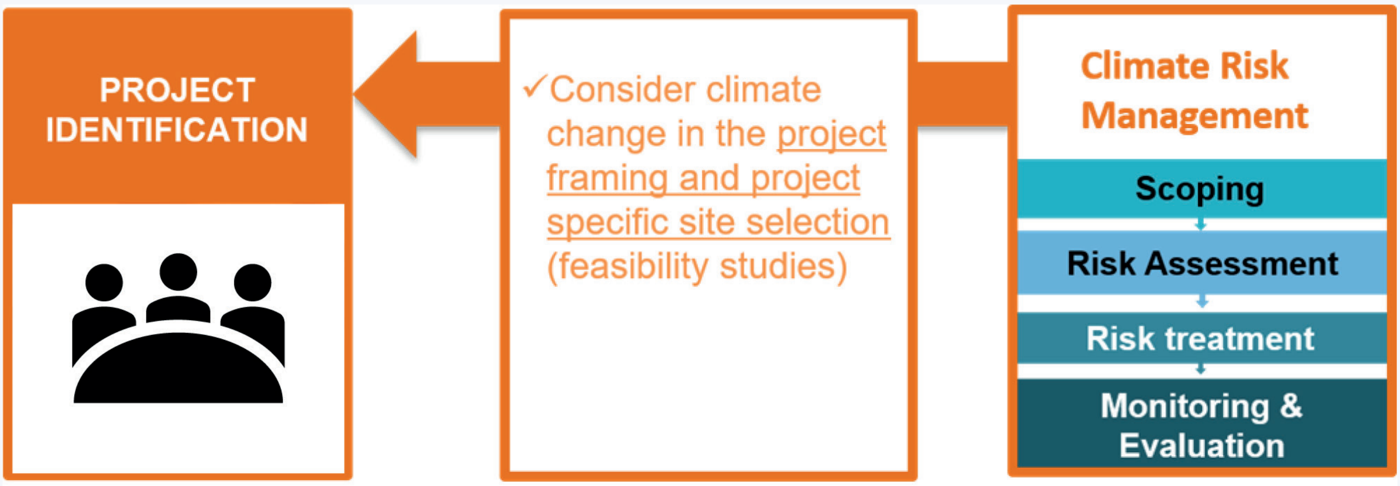
3. Identify, propose, and select measures to develop climate resilient BDPs or national plans and policies where types of projects are proposed that provide the intended service during their anticipated lifecycle and define climate change induced operational requirements at a basin level (dam cascades and implications etc.).

4. Mainstream and use the results into the entire BDP and especially into risk Assessment chapter of the BDP and modify BDP as appropriate on strategic objectives, proposal of recommendations for action and define how climate change needs to be considered for the project identification and preparation phase

Step 4 – Monitoring and Evaluation

1. Develop monitoring and evaluation plan that includes specific performance indicators and feedback into policy-making processes. Review latest advances in climate projections science and observed Data on the Catchment.
2. Develop a monitoring system of climate risks in the respective basin, closely monitor climate impacts such as the documentation of experienced damage and service reliability performances of the infrastructure projects implemented for periods of planning cycles.

4.2 Climate Proofing at the level of project identification



In the context of the NBI, the SAPs (NELSAP in the Nile equatorial lakes region and ENTRO in the eastern Nile region) play a catalytic role in identifying and driving forward regional investment projects, for example in the power sector.

Once an infrastructure project is being decided to be implemented as part of the implementation of e.g., a developed "Basin Development Plans" (BDP), the Identification phase of a project generally focuses on **scoping**, **inventory of candidate project options**, **pre-feasibility, concept, site selection**, and **preliminary costing** of likely projects.

In some cases, project identification may be done as part of national or regional water resource inventories rather than a project specific study.

The selection of one or more of those alternatives is being done using a criteria-based approach. One of the criteria includes a **cost-benefit ratio**, resulting in the selection of the **least cost project configuration**. Specific **project characteristics** are being defined. At this stage, there is **no detailed design**, and the project may not have funding approval. The level of data detail available is **generally low**, concept information is sufficient to generate preliminary cost estimates and for discussion with decision makers.

In this process IESEs (Initial environmental and social examination) are being carried out for each alternative location. The environmental and social appraisal will assess whether the project is capable of being implemented in accordance with the ESP and the PRs and include the assessment of the potential financial, legal, and reputational risks as well as identify potential environmental or social opportunities. The appraisal will be appropriate to the nature and scale of the project, commensurate with the level of environmental and social impacts and issues.

Step 1 – Scoping - Relationship to climate proofing

The coupling of IESE studies, that roughly estimate the social and environmental impacts of a project at a certain location, with climate studies can help reveal how the impacts of climate change may differentially affect the social and environmental impacts of a project depending on its location.

Key questions

- How might the social and environmental impactss of the project be affected by climate change at each of the alternative locations?
- How might climate risks related to the economic viability and service reliability of the project compare at each of the alternative locations?

Key outputs

- Risk and Opportunity Register reflecting, across alternative locations, the impacts of climate change on specific structural and operational components of the proposed project; and the potential effects of these impacts, at each alternative location, on the economic viability, service reliability, and social and environmental performance of the proposed project.
- List of potential climate proofing measures (structural, operational, and otherwise) that could help address risks or take advantage of opportunities posed by the changing climate at each of the alternative locations.

Ecosystem Based Adaptation considerations

Special Considerations for Ecosystem-based Adaptation During Project Identification:

Including EbA can influence risk assessments of project alternatives by introducing two new layers of risk: 1) risk to the natural assets used to implement EbA, and 2) moderated risk to grey/built assets due to EbA.

The introduction of co-benefits provided by EbA options may prompt the addition of new project selection criteria if those co-benefits are considered integral to overall project success. Developing indicators for EbA-related services requires a sufficient level of specificity to support project-level risk assessment and trade-off evaluation. The introduction of co-benefits provided by Ecosystem based Adaptation (EbA), options may prompt the addition of new project selection criteria if those co-benefits are considered integral to overall project success.

During the Problem Definition and Objective Setting stage, if EbA is to be included in a water infrastructure project as a climate-proofing measure, it is important to consider the implications for spatial, temporal, participatory, and jurisdictional scope. For example, it may be desirable to extend a project's spatial boundaries to include a wetland that provides water filtration or flood attenuation services downstream. If the supply of those services is only seasonal it may introduce new temporal considerations into the decision-making context. Extending the spatial boundaries may also mean the project now overlaps with the lands and interests of new groups such as private landowners, other domestic administrative jurisdictions, other countries, and/or Indigenous groups with unique rights (World Bank 2017). When this is true, it will increase the number of affected parties that should be engaged prior to identifying and selecting project alternatives for evaluation.

Step 2 – Risk Assessment

Main Objectives

This assessment builds on the climate risk assessment conducted for Basin Level Investment Planning, above, by addressing two main objectives.

1. To augment the prior climate, hydrological, hazard condition, and impact analyses with more location- and project-specific data and assumptions.

1. To more comprehensively evaluate risks and opportunities across each alternative location.

Approach

The focus of the assessment is now more project-location specific. Consideration should be given to the features of each alternative site that could have the most prominent effects on the design, operations, and/or performance of the project. Nonetheless, the assessment is not meant to provide a comprehensive design basis for the project(s). Rather, analyses should continue to use existing studies, indicator-based approaches, expert judgement, and, as relevant, the results of prior dynamic (e.g., hydrological) modelling efforts, to assess impacts, risks, and opportunities associated with each alternative location. Results should allow for a general comparison of climate-related risks and opportunities across the alternative locations.

1. Define the boundaries and main physiographic components of each alternative project location together with the EHCVs, that most influence the (sub) basin hydrology, and other flow influencing factors, like geomorphology or related environmental conditions. Considering key sub-basin-level characteristics and dynamics, adjust the set of EHCVs, and any related climate (hazard) indices, established for the risk assessment conducted during the Basin Level Investment Planning step; consider, as relevant, sub-basin.

1. Characterise the historical and future trends, variability, and extremes of each EHCV *at each alternative project location* by using historical data and GCM and/or RCM (Global and Regional Climate Model) projections for the (sub) basin(s), for the most recent Normal period and the near and far future (30 years, 60 years, etc.), respectively.

1. Estimate the character and potential magnitude of impacts *at each alternative location* associated with the historical and projected characteristics of the EHCVs in the (sub) basin.

1. Rank and evaluate risks using a defined scale *across alternative project locations*.

Hydroclimate data requirements

1. Use (sub) basin development maps and digital terrain models to determine projects' potential exposure to specific climate-related hazards (e.g., flooding, landslides) at each alternative location.

2. Initial EHCVs and, in some cases, threshold-informed indices, were identified and define for the Basin Level Investment Planning climate risk assessment. Build upon and refine these EHCVs and related indices, tailoring them, as relevant, by alternative project location.

3. Use climate and hydrological observations and projections for time periods of at least 30 years, for the refined set of EHCVs and related indices. In the absence of future hydrological projections (e.g., streamflow), use climate proxies (e.g., precipitation extremes as proxy for flooding). For the projections, use available global or regional (GCM/RCM-based) climate scenarios. statistically downscaled where possible.

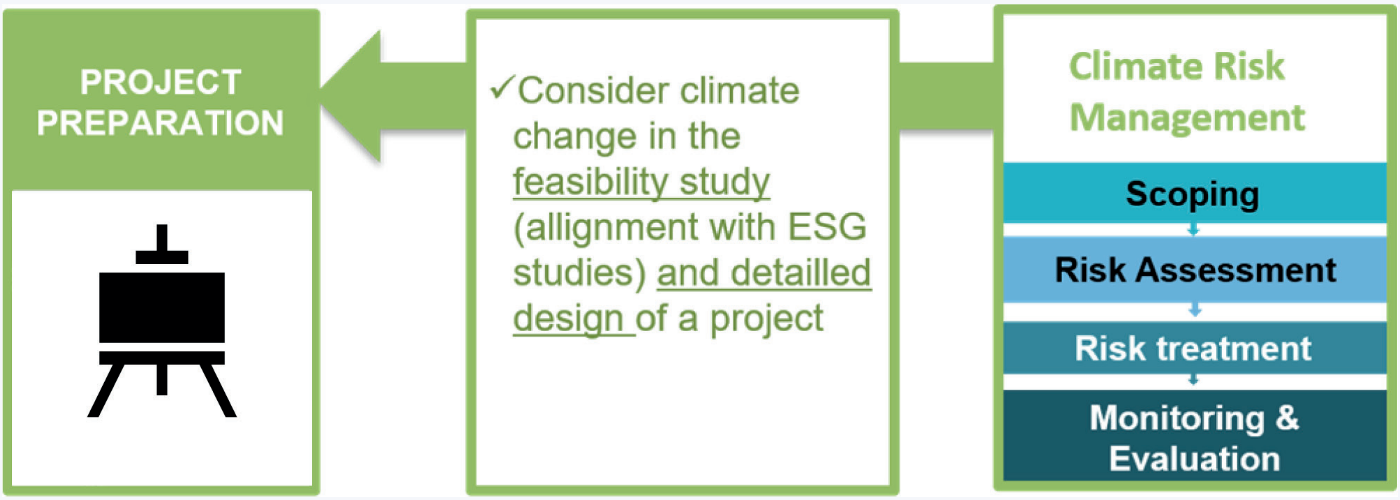
Step 3 – Risk Treatment

Select most appropriate project site with best NBV and EIRR considering climate change as an additional factor; and conduct resilience framing for the project (type of dam, necessary operational features, etc.) to ensure the resilience framing for the project preparation phase.

Step 4 – Monitoring and Evaluation

Monitor & re-assess whether key criteria for the investment are valid or need to be changed due to changing climate conditions.

4.3 Climate proofing at the level of project preparation



During the preparation phase, fieldwork is underway, feasibility studies are being conducted, detailed design is in progress, and costing is being developed. Economic and finance Analysis (EFA) and Environmental and Social Impact Assessments (ESIA) for remaining candidate projects are being executed to determine their viability and select the best performing project and location. The level of detail is significantly more demanding than in the Identification phase.

Feasibility studies are a comprehensive analysis and detailed study of the contemplated project directed towards its approval, financing, design and construction. The engineering (technical), economic (EFA) and social-environmental (ESIA) feasibility for the candidate projects are determined at this stage, to determine their viability and select the best performing project(s) and location(s). The information from this stage is used by the project owners to decide whether or not to go for implementation of the project., i.e., to proceed with definite plan studies, final design and construction of the project. During the feasibility study, the project owner will usually apply for all the legal licences necessary to develop the project. Feasibility study provides the basis for resource mobilization, i.e., appropriation of funds and negotiation of loans from financing institutions for the design and construction of the project. Note that political and other secondary effects may also be factors in not choosing a project. If the technical and economic feasibility of the project is proven, and the approval of the project is received, then the definite planning (detailed design) is undertaken.

During the detailed design, the information from the feasibility study stage is extended and supplemented to provide detailed final plans and specifications from which tenders can be invited and construction contracts awarded.

A detailed description of typical activities carried out at this stage is available in a number of project development manuals, for example the Hydropower Development series published by the Norwegian Institute of Technology (Ravn, 1992, Volume 5).

Step 1 – Scoping - Relationship to climate proofing

Project feasibility studies and project design must reflect recent climate variability and extremes as well as conditions projected to occur over the full planned service life of the proposed project, under different potential climate change scenarios. The economic viability and service reliability of the proposed project must be understood within the context of climate change. So too must the eventual social and environmental impacts of the proposed project.

Key questions

- How and to what degree might climate change affect the economic viability, service reliability, and environmental and social impacts of the proposed project at the chosen location?
- Which specific infrastructure assets, components, or operational procedures may be most vulnerable to the impacts of climate change, and most affect the economic viability, service reliability, and social and environmental outcomes of the proposed project at the chosen location?
- What are the best options for improving the climate resiliency of the proposed project, over all relevant time horizons, at the chosen location?

Key outputs

- ESA and EFIA reports that convey project risks for the chosen location according to a range of different climate change scenarios and related hazards.
- Project design options for the chosen location that evaluate economic viability, service reliability, and social and environmental outcomes based on an agreed set of climate change scenarios (including hazards, risks, and opportunities) and climate proofing measures.
- Provisional project design specifications that describe and justify preferred climate proofing measures and suggest related performance monitoring and evaluation plans.
- Draft Stand-Alone Climate Resilience and Disaster Risk Management Plan.

Ecosystem Based Adaptation considerations

Special Considerations for Ecosystem-based Adaptation During **Project Preparation:**

Because they can often rely on “free” maintenance and other supporting services provided by nature, natural assets used for EbA have different characteristics than built/grey infrastructure that should be considered during in-depth feasibility assessments and climate stress testing (e.g., potentially longer, more dynamic deterioration timelines).

Previously unconsidered EbA options may be useful as additional risk treatments during Project Preparation.

Step 2 – Risk Assessment

Main Objectives

This assessment builds on the prior two iterations of climate risk assessment by addressing two main objectives.

- To conduct a project component-level risk assessment that supports evaluations of project feasibility and informs overall design.
- To produce information concerning project structural design and service reliability, aligned with requirements for cost-benefit analyses, siting decisions, and economic loss estimates.

Approach

The focus of the assessment is now on the specific components of the project(s). The assessment should continue using indicator-based approaches and expert judgement but will also need to draw of key types of dynamic (e.g., hydrological) modelling (simulation) tailored for the location and project. Results should allow for the comparison of alternative design options with respect to the management of climate-related risks in the specified sub-basin and for the defined project. The approach should include:

- Detailed definitions (design drawings, surveys, economic data) of project assets and components.
- Detailed, single location-simulation of project function, including changes in service provision under future climate conditions (e.g., discharge, floods and floods return periods, evaporation, sediment loads, slope stability, etc.).
- Risk assessment of specific structural and operational components and services of the specific project(s).

Hydroclimate data requirements

- Use (sub)basin and location-specific development maps and digital terrain models to determine projects' potential exposure to specific climate-related hazards (e.g., flooding, landslides) at the particular location.
- Further augment and refine, as relevant, the EHCVs and threshold-based indices identified and defined during prior investment cycle steps (1, 2). In so doing, address the relationship between coping range, critical thresholds, vulnerability, and a climate-related success criteria for all main components and operational requirements of the project. These indices and related statistics are needed to stress-test potential alternative design thresholds, considering suture changes in climate.
- Use climate and hydrological observations and projections for time periods of at least 30 years, for the refined set of EHCVs and related indices. Use future hydrological projections (e.g., streamflow); if they do not yet exist develop and run these simulations.
- To help ensure all historical extreme precipitation events are as well identified and characterised as possible, use satellite and quantitative radar data and estimates where possible.
- For climate projections, use high-resolution scenarios from RCMs (with bias correction or statistical downscaling applied) to provide inputs for hydrological models and otherwise assess the climate vulnerabilities and risks associated with the development option, i.e., likelihood of exceedances of design an/or operational thresholds and related impactss for the performance of the project.
- To stress-test project design and operational thresholds, adopt a probabilistic approach to data generation, based upon:
  - downscaled RCM data for input into dynamic risk models, to compare present day to future risk levels
  - longer time scales to better reflect the eventual magnitude of the most extreme events (e.g., 200 years of projected data provide better indication of the character of the 500-year event than do.
  - a stochastic weather simulation model ("weather generator") to simulate the longer time periods and related extremes (e.g., PMP and PMF).

Step 3 – Risk Treatment

This stage is about managing the risks of the project. Its objective is to "modify the project design (and/or create a project design that is adaptable) to ensure that it leads to a climate proof (resilient) project that is at the same time cost effective and economically feasible. The process is focusing on modification of key technical, environmental, and social design parameters of the project, taking account of climate change and especially implement measures for the climate resilient budgeting, design, operation, and maintenance of the infrastructure.

This should be able to lead to

- A climate resilient project design and implementation.
- A Climate Risk Management Plan to monitor if interventions are implemented, and new risks are handled during the Implementation and Operation phase.

Step 4 – Monitoring and Evaluation

- Re-Assess whether identified measures have been proofed successful and viable.

4.4 Climate proofing at the level of resource mobilization

In the Resource Mobilization phase, projects are seeking funding and approval. For mobilizing funding and negotiating insurance schemes, nowadays climate proofing is a requirement. The project planners, designers and future operations must proof that the financial proposal is resilient to climate change impacts. As such it should be possible to establish the probability of the project not meeting a given financial criteria within a given time horizon. Climate proofing may require additional capital investments (depending on the adaptation or mitigation measures that are adopted.

This typically calls for high levels of detail. Funders and regulators want to have a precise understanding of the project. Fortunately, the design is complete and high levels of data detail are available. Resource mobilization should be integrated into project activities right from the beginning of the project. This is done by taking into consideration the impacts on the project financial feasibility of the different climate stressors.

The key financial and economic metrics of the project such as

- Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyse the profitability of a projected investment or project.
- The internal rate of return (IRR) is a metric used in capital budgeting to estimate the profitability of potential investments. The internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. IRR calculations rely on the same formula as NPV does

- Unit price/ cost of the services and maintenance costs should be estimated during the pre-feasibility and feasibility stages and updated during the project design and implementation stages. The cost of the services can be an important threshold in development projects.

Relationship to climate proofing

To access project funding and negotiate insurance it will be necessary to demonstrate the long-term economic viability, service reliability, and social and environmental performance of projects in the context of climate change. This requires demonstrating, among other things, the likelihood that projects will meet given financial targets over specific time horizons under a range of future climate change scenarios. Meanwhile, maintaining economic viability under climate change may require adoption of specific climate proofing measures – structural, operational, or otherwise – and securing related capital investments.

Key questions

- How might projected climate change affect the estimated costs and benefits of the project?
- What range of climate proofing measures should be considered for the project?
- If there are multiple technically feasible and economically desirable climate-proofing measures, which of these should be recommended and why?
- Should the co-benefits associated with certain climate-proofing measures, such as ecosystem-based approaches, be included in the economic analysis?
- If climate proofing is desirable, when is the best time to undertake such investments over the lifetime of the project?

Key outputs

- Final Project Plan demonstrating economic viability and service reliability of the project under a range of climate change scenarios (including related hazards, risks, and opportunities).
- Final Project Design Specifications, including specific climate proofing measures for:
    - immediate integration within the project.
    - partial or staged integration within the project.
    - eventual implementation within the project, depending on the character and pace change in key climate conditions.
- Final Stand-Alone Climate Risk Management Plan (eventual).
- Updated Risk Matrix documenting which risks are being treated within the chosen funding and insurance strategy.
- Monitoring and Evaluation Plan for priority climate risks.

Ecosystem Based Adaptation considerations

Special Considerations for Ecosystem-based Adaptation During **Resource Mobilization:**

Doing cost-benefit analysis for EbA options can be quite different from doing the same for hard/grey infrastructure alternatives because some ecosystem services provided by EbA options are not bought and sold in markets (especially co-benefits like habitat and recreation opportunities). This "non-market value" to society requires special economic valuation techniques to assign monetary values to non-market goods and services so the net benefits of a project can be compared on a common scale.

Step 2 – Risk Assessment

Main Objectives

This assessment builds on the prior three iterations of climate risk assessment by addressing two main objectives:

- demonstrate in a detailed fashion the financial performance, and quantify residual risks, of the project under different climate scenarios.
- make explicit the nature and cost of different potential adaptation measures proposed for design or operation of the project

Approach

The focus of the assessment is now on the financial and economic performance of the project over time.

The assessment should use these results of the climate stress tests, and the updated risk matrix, from investment cycle step 3, to further deepen and document the financial and economic impacts of climate change for the project over time; different adaptation measures and financing strategies should be considered to establish measures of financial and economic return.

Data requirements:

- The detailed climate change vulnerability and risk assessment of investment cycle step 3, Project Preparation, characterises causal relationships between the projected or anticipated impacts of climate change and the performance and/or physical integrity of each infrastructure asset, down the component level. The physical and economic thresholds, and impacts, characterised through this prior assessment should be used to assess in greater depth and the financial and economic project performance of the project, under the full range of adopted climate change scenarios and adaptation options.

- Economic and financial data will be required for cost-benefit analysis, ROI and other types of analyses based on climate-proofing (adaptation) and non-adaptation options

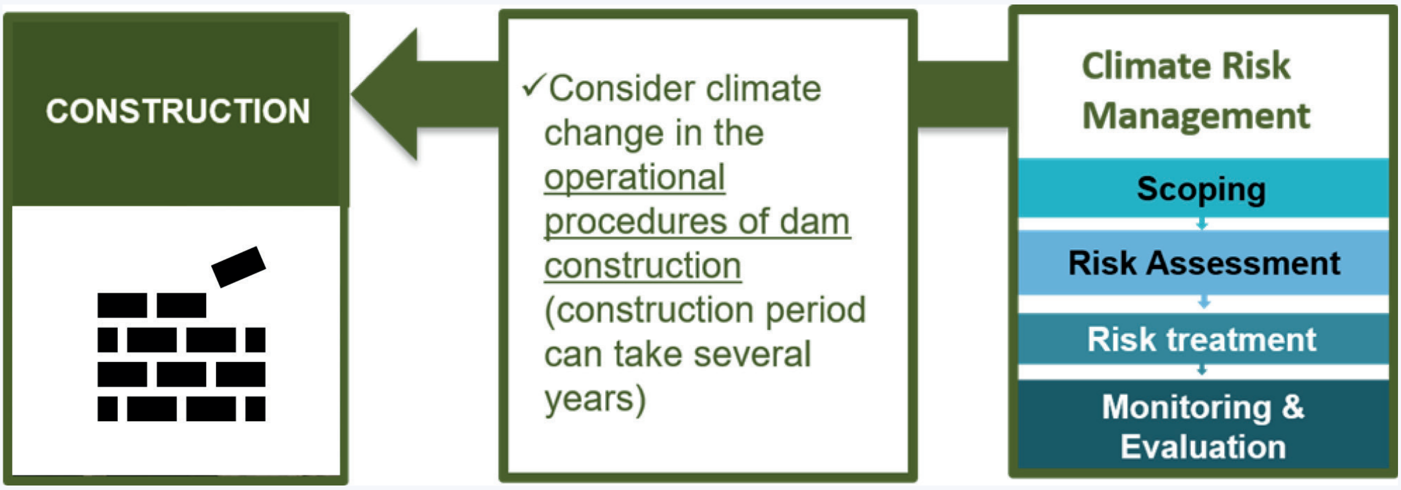
Step 3 – Risk Treatment

- Climate resilient insurance policy covering climate risks (monetary loss) identified and contracted.

Step 4 – Monitoring and Evaluation

- Re-Assess whether policies contracted cover current & future climate risks.

4.5 Climate proofing at the level of construction



The Implementation and Construction phase of the project generally requires high levels of detail. At this stage, the project is tendering, construction is underway, and manuals and guidance are being prepared. Rigorous training may be required to support start-up and early operation of the project. A lot of data detail is available because the design is done. Climate work done at this stage will require supporting or aligning with these high levels of detail. Moreover, (infra)structures will be setup and removed after construction that support the overall successful implementation of the project

Step 1 –Scoping – Relationship to climate proofing

The construction of large projects can take many years. During this time, new evidence may emerge about the pace or character of climate change, and about related risks. Climate-proofed designs may need to be updated as a result. Moreover, during construction, site preparation and management should consider the potential for extreme weather events that may damage equipment, threaten human health and safety, impact temporary structures (for example coffer dams), and/or cause environmental damage (siltation, chemical spills).

Key Questions

- Could any temporary, construction-related infrastructure be at risk because of climate variability or change, extreme weather?
- Have there been any consequential advancements in the understanding of climate change and related risks in the region, during the construction phase of the project, that can be taken into consideration?

Key outputs

- Updated Risk and Opportunity Register
- Updated Climate Risk Management Plan, including documentation of implemented climate proofing measures (structural and non-structural), and of unplanned project modifications made during construction (see bullet point below).

Record of modifications made during construction (all of which should be stress-tested for any climate related sensitivities).

Ecosystem Based Adaptation considerations

Special Considerations for Ecosystem-based Adaptation During **Construction:**

EbA options can require different materials than grey/built infrastructure and these materials need to be sourced to ensure adequate supply during construction (e.g., sand and gravel for river re-meandering, seedlings for riparian planting). Personnel may also be needed with different expertise for the application of these materials.

Step 2 – Risk Assessment

Main Objectives

In many cases, this step of the investment cycle will not itself require any further climate change risk assessment. However, if major design modifications or changes to site management practices become necessary, because, for example, new findings become available related to the impacts of climate change in the region, basin, or sub-basin, further analysis of critical project design thresholds most sensitive to climate may need to be carried out. In this case, the risk assessment approach described for project preparation (step 3 above) applies.

During construction, it is also important to monitor climate hazards, to support early warning systems and help prevent damage to the project and the surrounding environment.

Approach

As indicated under "main objectives," should further risk assessment be required during this step of the investment cycle, it should largely conform with the approach used in project preparation (step 3 above).

Consideration should be given to:

- Any major project design modifications or site management practices that have become necessary and may be climate-sensitive

- Construction-related infrastructure that may not have been assessed as part of the project during prior investment cycle steps.

- Further analysis of critical project design thresholds most sensitive to climate, especially if relevant new findings have become available regarding the impacts of climate change in the region, basin, or sub-basin; and for infrastructure assets that support the construction and may not yet have been assessed.

Hydroclimate data requirements

Hydroclimate data requirements conform to those of step 3, project preparation. However, the following options should also be considered:

- satellite and radar data for specific events that occur during construction of the project, if one or more these events might help improve understanding of local extremes and therefore inform more detailed sensitivity analyses of one or more components of the project.

- analysis of climate risks and test robustness of critical design components to a range of climate futures (e.g., how does the flood which occurred during construction compare to projected flood return levels? What if the historical flood is projected to occur and be exceeded frequently in the future?)

- use of any new analyses specifically to refine climate resilience measures from Project Preparation step (3) and reflect these refinements in the detailed engineering designs.

Step 3 – Risk Treatment

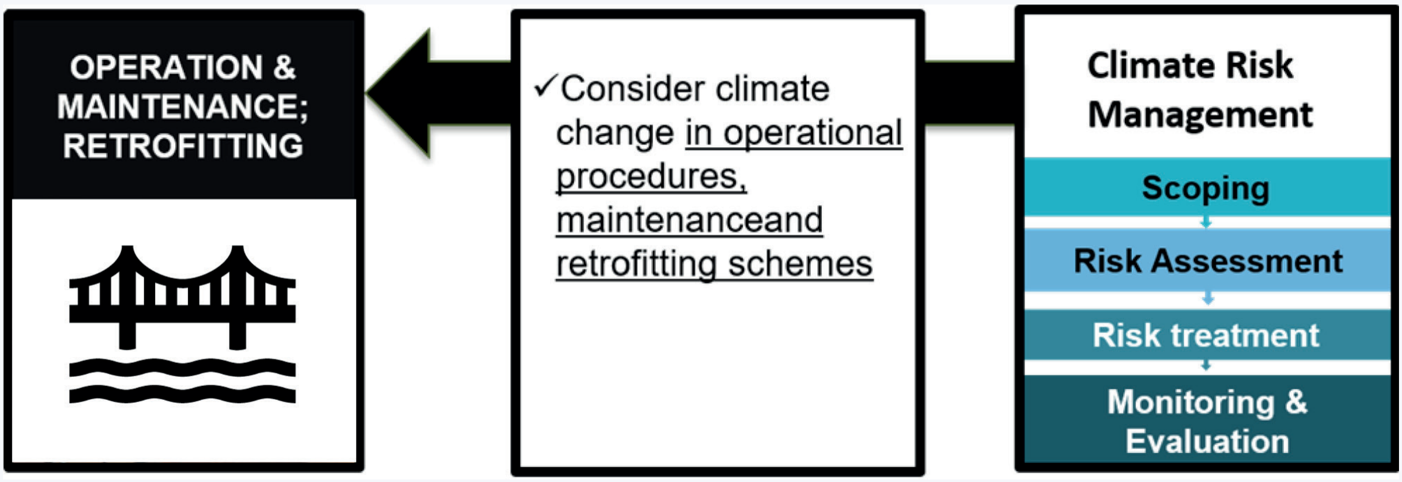
Development and implementation of standard operating procedures (SOPs) for the construction site regarding warning and immediate response options to protection of assets and people in case of climate related extreme events.

Approaches to mitigating runoff from and sedimentation because of cleared ground may require different climate analyses than what would have been conducted to inform project design and, later, operations. In such cases, the new designs may have to be checked for their resilience using the approach defined under the project preparation stage.

Step 4 – Monitoring and Evaluation

Re-Assess performance of these SOPs and adaptation measures during construction. Update the CRMP if any major modifications to the project have been made. Monitor and Evaluate progress on climate proofing following the Monitoring, Evaluation and Reporting (MER) plan prepared at Project Preparation Stage. Apply approaches to collecting performance data with respect to, e.g., asset conditions, including recorded changes in condition as the result of climate-related stressors – forensic information to inform remediation / renewal decisions, etc.

4.6 Climate proofing at the level of operation, maintenance or retrofitting



The operation stage commences once a project is commissioned. The Operation and Maintenance phase covers four key activities:

- the operation of the project
- maintenance
- refurbishment
- and ultimately the end of life and retirement of the project

Operation should be done at a cost reflective price that ensures the profitability and sustainability of the infrastructure. Profitability and sustainability can be from investment, social, environmental and safety perspectives. In addition to achieving the infrastructure owner's objectives, there is country specific regulatory requirements for issues such as dam safety, reliability to provide the service and social and environmental performance.

Step 1 – Scoping – Relationship to climate proofing

Because of the long service life (>100 years) of some assets, the frequency and intensity of climate hazards will likely change, perhaps markedly, before refurbishment or decommissioning. There may be the need for additional climate proofing measures as a result. Climate proofing measures implemented during the operation and maintenance phase of a project can focus on the physical structure, on health, safety, and emergency management policies, or asset monitoring and maintenance systems. An important mechanism for identifying the need for new climate proofing measures is the dam safety review process, carried out at least every 15 years. The goal of the dam safety framework should be to ensure a uniform high level of safety of Nile Basin dams and related structures; changing climate conditions should be considered as part of these reviews, to ensure these structures do not pose a threat to life, property, or the environment.

Key questions

Is the performance of the infrastructure potentially at risk due to changes in the climate-related hazards that do not conform to design- or operations and maintenance-related assumptions?

Key outputs

- Updated Risk and Opportunity Register
- Updated Climate Risk Management and Dam Safety Plan, documenting any new structural and non- structural climate proofing measures, the latter of which can also include further monitoring.

Ecosystem Based Adaptation considerations

Special Considerations for Ecosystem-based Adaptation During **Operations & Maintenance:**

Unique monitoring considerations for EbA include: 1) complex, long-term changes involving multiple system-drivers, 2) difficult-to-define causal pathways leading to social and ecological impacts, 3) no universal set of indicators appropriate for each site, 4) longer time horizons to observe EbA benefits, and 5) potential provision of a portfolio of services by a single EbA.

Step 2 – Risk Assessment

Main Objectives

Periodic assessments during project operation are meant to address two main objectives:

- monitoring of changing climate-related risks over time, whether because of changes in the infrastructure or its operating environment and their interactions with the changing climate.
- identification, assessment, and evaluation of new risks associated with the changing climate.

Approach

The risk assessment approach described for project preparation generally applies and the assessment conducted during that step (3) should be built upon. Where possible:

- work from and further ela ate and update existing risk matrices

- adjust impact thresholds based on the physical condition of the infrastructure and its components at present time
- recalculate probability and impact analyses.

A key consideration is that the aging infrastructure will likely be experiencing changing loads because of climate change, as well as other changing environmental and operational conditions.

Hydroclimate data requirements

Use all data sets mentioned in this guide for climate risk assessment of the infrastructure, as needed.

Step 3 – Risk Treatment

In case changes in risks are identified, identification and selection of measures to increase the resilience of the physical and operational components of the infrastructure and updating and implementing a climate resilient dam safety management plan.

Step 4 – Monitoring and Evaluation

- In case changes in risks are identified, provide feedback into the entire investment cycle where appropriate
- For long-lived infrastructure, regular monitoring should be undertaken of the environment and adaptation measures to ensure that they are providing the expected level of risk reduction.

5 ANNEX

5.1 Guidelines from the international community

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5.4 Key Terms

Adaptation

Process of adjustment to actual or expected climate and its effects.

- In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities.
- In some natural systems, human intervention can facilitate adjustment to expected climate and its effects.
  ISO 14090, IPCC.

Adaptive Capacity

The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to impacts. (ISO 14090, IPCC).

Climate Hazard

Specific impactful event as related to the broader climate parameter category.

Climate Hazard Indicator

Specific climate values (Maximum Temperature > 35 C; Precipitation > 100mm; Freezing Rain > 30 mm, etc.) ISO 14090.

Climate Parameter

Broader categories of climate that contain specific climate hazards or indicators. Climate parameters include temperature, precipitation, sea-level rise, wind, etc. (ISO 14090, IPCC).

Climate Scenario

A plausible representation of future climate that has been constructed for use to investigate the potential impacts of anthropogenic climate change. Various representations of climate scenarios exist from iterations of IPCC Reports, including Representative Concentration Pathways (RCP) from IPCC AR5, Shared Socioeconomic Pathways (SSP) from IPCC AR6, and Global Warming Levels (GWL). While specific details surrounding scenarios may change with time, it is important to consider a range of scenarios in climate risk analysis. For example, RCP 8.5 from AR5 is considered a high scenario or 'business as usual scenario,' if past practices driving emissions continue. RCP 8.5 is used in many climate risk assessments. Scenario choice is often tied to risk appetite of the project team and/or sponsoring organization. (Climate Risk Institute).

Impact Outcome of an event affecting objectives.

- An event can lead to a range of impacts.
- A impact can be certain or uncertain and can have positive or negative effects on objectives.
- Impacts can be expressed qualitatively or quantitatively.
  (ISO Guide 73).

Element

A distinct part of a composite system. Could include physical, planning or human resources. (ISO 14090).

Engineering Vulnerability

The shortfall in the ability of public infrastructure to absorb the negative effects, and benefit from the positive effects, of changes in the climate conditions used to design and operate infrastructure. (PIEVC).

Enterprise Risk Management	The culture, capabilities, and practices, integrated with strategy-setting and its performance, that organizations rely on to manage risk in creating, preserving, and realizing value. (COSO).
Likelihood	Chance of something happening. • In risk management terminology, the word "likelihood" is used to refer to the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically. • The English term "likelihood" does not have a direct equivalent in some languages; instead, the equivalent of the term "probability" is often used. However, in English, "probability" is often narrowly interpreted as a mathematical term. (ISO Guide 73). Likelihood: Chance of something occurring; within the context of climate risk assessment, the chance of a defined climate hazard over a given time horizon. Climate Scenario: A plausible representation of future climate that has been constructed for use to investigate the potential impacts of anthropogenic climate change. Various representations of climate scenarios exist from iterations of IPCC Reports, including Representative Concentration Pathways (RCP) from IPCC AR5, Shared Socioeconomic Pathways (SSP) from IPCC AR6, and Global Warming Levels (GWL). While specific details surrounding scenarios may change with time, it is important to consider a range of scenarios in climate risk analysis. For example, RCP 8.5 from AR5 is considered a high scenario or 'business as usual scenario,' if past practices driving emissions continue. RCP 8.5 is used in many climate risk assessments. Scenario choice is often tied to risk appetite (tolerance) of the project team. Adaptation: Process of adjustment to actual or expected climate and its effects. Residual Risk: Risk remaining after risk treatment.
Resilience	The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation. (IPCC)
Risk	Effect of uncertainty • An effect is a deviation from the expected. It can be positive, negative or both. • An effect can arise as a result of a response, or failure to respond, to an opportunity or threat related to objectives. • Uncertainty is the state, even partial, of deficiency of information retaliated to, understanding, or knowledge of, an event, its Impact, or likelihood. This guide applies the following formula as a measure of risk. Risk = Exposure x Likelihood x Impact.

Risk Appetite	Amount and type of risk that an organization is willing to pursue or retain. (ISO Guide 73)
Risk Owner	Person or entity with the accountability and authority to manage a risk.
Risk Profile	Description of any set of risks. The set of risks can contain those that relate to the whole organization, part of the organization, or as otherwise defined. Risk Tolerance: Readiness to bear the risk after risk treatment. Organization's or stakeholder's readiness to bear the risk after risk treatment in order to achieve its objectives. Risk tolerance can be influenced by legal or regulatory requirements.

Risk Treatment	Process to modify risk.
	• Risk treatment can involve:
	  ◦ Avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk
	  ◦ Taking or increasing risk in order to pursue an opportunity
	  ◦ Removing the risk source
	  ◦ Changing the likelihood
	  ◦ Changing the Impacts
	  ◦ Sharing the risk with another party or parties [including contracts and risk financing]
	  ◦ Retaining the risk by informed decision
	• Risk treatments that deal with negative impacts are sometimes referred to as "risk mitigation", "risk elimination", "risk prevention" and "risk reduction".
	• Risk treatment can create new risks or modify existing risks.

Traditional Knowledge	Although there is no universally accepted definition of "traditional knowledge", the term is commonly understood to refer to collective knowledge of traditions used by Indigenous groups to sustain and adapt themselves to their environment over time. This information is passed on from one generation to the next within the Indigenous group. Such Traditional Knowledge is unique to Indigenous communities and is rooted in the rich culture of its peoples. The knowledge may be passed down in many ways, including Storytelling, Ceremonies, Dances, Traditions, Arts and Crafts, Ideologies, Hunting, Trapping, Food Gathering, Food Preparation and Storage, Spirituality, Beliefs, Teachings, Innovations, Medicines. Traditional Knowledge is usually shared among Elders, healers, or hunters and gatherers, and is passed on to the next generation through ceremonies, stories or teachings.
Threshold	Point beyond which a system is deemed to be no longer effective: Economically; Socially; Technologically; or environmentally. Also known as tipping point. (ISO 14090).
Vulnerability	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. (ISO 14090, IPCC).

5.5 Types of infrastructure impacts and adaptation options

Table 12 Possible impacts and potential measures for physical components (partly adapted from World bank's climate resilience guidelines for hydropower)

Project component	Climatic variable	Impacts on project component	Potential resilience measures in the domains: hazard mitigation, exposure reduction, increase of robustness, protection, and residual risk management
Access roads and camps	Tempera-ture	High temperatures damage road con-struction	Additional construction joints Suitable pavement materials for temperature variations
	Precipita-tion and streamflow	Heavy downpours damaging unsur-faced roads	Increased drainage Surface/gravel the road Amend road design (e.g. additional camber) Increased provisions and allowances for O&M
		Increased flows in culverts, bridges and road/camp drainage	Culvert, bridge and drainage sizing considering hydrological uncertainties Robust assessment of camp location
		Increased debris from higher or flashy surface run-off	Debris screens Increased maintenance
		Increased risk of slope instability triggered by sur-face runoff and groundwater	Increased landslide hazard assessments Additional slope Protection Additional crossing More robust assessment of road alignment
River diversion works	Precipita-tion and streamflow	Increased flashy or sustained high flow events (floods during construc-tion)	Design for higher return period and considering hydrological uncertainties Flood forecasting for construction period For concrete dams, accepting and organizing overtopping of construction work
		Lack of low-flow period for riverbed construction	Construction planning for minimal low flow period
Dam and appurtenant works (includ-ing spillway, intake struc-ture, bottom outlets, sediment handling structures, etc.)	Precipita-tion and streamflow	Spillway is of insuf-ficient size to pass floods leading to safety issues for dam (e.g. for adap-tation of existing projects)	Increase spillway capacity Add additional spillway/fuse gates Use of labyrinth or piano keys weirs Rubber dams Reassess dam type to allow overtopping (i.e. a concrete dam) Increase freeboard or allowance for flood rise Add upstream parapet/wave wall on dam crest
		Increased risk of slope instability (surface water triggered failures and ground water induced failures) (e.g. for adaptation of existing projects)	Additional slope protection and stabilization measures Slope stability monitoring/ surveying Reassessment of dam location or alignment

Table 12 Possible impacts and potential measures for physical components (partly adapted from World bank's climate resilience guidelines for hydropower)

Project component	Climatic variable	Impacts on project component	Potential resilience measures in the domains: hazard mitigation, exposure reduction, increase of robustness, protection, and residual risk management
		Changed environmental flows (for fish, fish passage systems, water quality, navigation)	Design environmental flow capacity with potential for varying discharge rates Design the environmental flow system so that it can be adapted in the future if ecological flow requirements change Design fish passage system(s) with potential for varying discharge rates and considering climate change
		Erosion at toe of dam due to increased spillway discharge	Relocation of spillway to ensure floods are discharged downstream of powerhouse (e.g. into a secondary channel or by extending the spillway beyond a powerhouse at the toe of the dam) Increased energy dissipation from spillway Increased stilling basin capacity and protection
	Temperature	Material expansion/ contraction causing cracking leading to leakage or instability	Additional monoliths and/or construction joints Change of concrete mix designs to be more resilient to temperature variations Change of dam type/choice of construction materials Dam concrete temperature control by pre or post cooling
		Construction using certain materials (e.g. concrete placing or dam clay core) cannot take place in extreme temperatures	Construction planning to consider extreme temperature variations. This may require additional measures during construction (e.g. ice for concrete construction) or revised construction scheduling
	Wind	Increased wave height and freeboard requirement for dams	Ensure freeboard calculations account for potential increases in wind loading
		Increased wind loading on structures (dam, buildings, gates, etc. transmission towers etc.)	Ensure design for wind loading account for potential increases in wind loading
Reservoir	Precipitation and streamflow	Increased sediment load resulting in loss of storage or additional flushing frequency (if designed for flushing).	Additional flushing and sediment management facilities Change in operation methodology Incorporate catchment erosion control plan Raising of dam crest to increase live storage Development of upstream sediment control facilities
		Reservoir slope instability causing landslides and trees falling into reservoir	Detailed reservoir rim stability assessment leading to slope stabilization in risk areas

Table 12 Possible impacts and potential measures for physical components (partly adapted from World bank's climate resilience guidelines for hydropower)

Project component	Climatic variable	Impacts on project component	Potential resilience measures in the domains: hazard mitigation, exposure reduction, increase of robustness, protection, and residual risk management
		Change of river regime with reduced base flow and increased floods	Increased spillway capacity to allow increased flow Consider changing operating methodology to capture increased flood in storage projects Incorporate provision for future increase of the storage capacity by dam and FSL raising
		Increased trash and vegetation in reservoir from increased run-off	Additional trash rakes, types of trash screens and frequency of trash removal or automation or a more robust system design
		Increased/decreased sediment loads impacting operating regime of reservoir	Additional flushing and sediment management facilities e.g. increased temporary storage for sediment where the as a desander. Change in operation methodology Allow excavation of coarse and sand construction material by locals at reservoir tail Additional dredging
		Additional floating vegetation/ algae potentially clogging intakes	Consider adding overtopping facility for reservoir surface cleaning Add intake trash rack rake equipment
	Temperature	Increased evaporation losses leading to reduced water for generation	Account for losses in power-energy modelling Floating solar/reservoir surface coverage
		Water temperature (fouling, oxygen content, stagnation and fish kills)	Operating and maintenance monitoring
	Air composition	Increased CO_2 in atmosphere stimulates plant growth in reservoir with negative impacts on intake screens	Ensure intake is designed with suitable track racks/rakes and O&M is considered in design
	Irradiance	Increases on reservoir water temperature	
Intakes and waterways (e.g., delivery Canals and tunnels)	Precipitation and streamflow	Increased flows through waterways	Design for higher flows Design with potential for easily increasing capacity
		Increased risk of slope instability (surface water triggered failures and ground water induced failures)	Additional slope protection and stabilization measures Slope stability monitoring/ surveying Reassessment of waterways location or alignment
		Increased sediment deposition leading to diminished flows	Include desander basins Additional slope protection measures Slope stability monitoring /surveying Design of intakes, canals, tunnels, etc. with due consideration of sediment problems Periodic maintenance of diversion headworks and canals for runoff-river plants and irrigation systems

Table 12 Possible impacts and potential measures for physical components (partly adapted from World bank's climate resilience guidelines for hydropower)

Project component	Climatic variable	Impacts on project component	Potential resilience measures in the domains: hazard mitigation, exposure reduction, increase of robustness, protection, and residual risk management
	Temperature	Material durability issues and expansion/contraction causing cracking leading to leakage, instability or aesthetic issues	Additional monoliths and/or construction joints Change of concrete mix designs to be more resilient to temperature variations Change of construction materials
Powerhouse, tailrace and switchyard	Precipitation and streamflow	Flooding of powerhouse due to increased fluvial flow	Increased flood defenses for powerhouse Relocation of powerhouse to higher ground Surface powerhouse to be relocated underground to improve resilience to fluvial flooding Relocation of spillway to ensure floods are discharged downstream of powerhouse (e.g. into a secondary channel or by extending the spillway beyond a powerhouse at the toe of the dam)
		Flooding of powerhouse from direct precipitation	Increased drainage provision in and around powerhouse
		Increased risk of slope instability (surface water triggered failures and ground water induced failures)	Additional slope protection and stabilization measures Slope stability monitoring/ surveying Reassessment of powerhouse location or alignment
		Higher/lower flows available for increased/decreased installed capacity	Increased powerhouse civil works to be adaptable for future additions of electromechanical equipment (e.g. space in powerhouse for additional turbines and generators) Tailrace maximum capacity to be increased to allow for potential higher discharges
	Temperature	Increased/decreased temperature within powerhouse causing problems for people and equipment	Air-conditioning/heating requirement, insulation, ventilation (natural, mechanical) Moisture control (mould, condensation, damp-proofing)
		Increased/decreased temperature causing problems with concrete placement during construction of powerhouse	Additional construction joints Change of concrete mix designs to be more resilient to temperature variations Change of construction materials
		Material durability issues And expansion/contraction causing cracking leading to leakage, instability or aesthetic issues	Additional monoliths and/or construction joints Change of concrete mix designs to be more resilient to temperature variations Change of construction materials
Electro-mechanical Equipment	Precipitation and streamflow	Increased flows to be passed through turbines	Installation of variable speed turbines or turbines with higher efficiency for a wide range of discharges
		Varied flows result in different sediment loads which can cause turbine erosion	Install corrosive resistant turbine blades

Table 12 Possible impacts and potential measures for physical components (partly adapted from World bank's climate resilience guidelines for hydropower)

Project component	Climatic variable	Impacts on project component	Potential resilience measures in the domains: hazard mitigation, exposure reduction, increase of robustness, protection, and residual risk management
	Temperature	Cooling water (sizing, blockage due to vegetation / algae)	Design for increased uncertainty
		Corrosion resistance (more aggressive at high temperatures)	Install corrosive resistant turbine blades
		Operating temperatures (impacts on serviceability, durability, ratings)	Design for increased uncertainty
Transmission Lines	Precipitation and streamflow	Increased risk of slope instability (surface water triggered failures and ground water induced failures)	Additional slope protection and stabilization measures Slope stability monitoring/ surveying Reassessment of transmission tower location and line alignment Design transmission tower foundations for greater stability uncertainty
		Flooding along transmission line route	Route selection (avoid flood plains, steep slopes)
	Temperature	Temperature effects on conductor capacity	Amend specification of conductors to be more resilient for a range of temperatures Thermal effects on conductor loads
		Lightning protection (changed risk)	Ensure transmission towers are designed for lightening risk
		Atmospheric changes affecting solar radiation/solar flares	
		Increased dust on insulators	Design protection for insulators
		Increased frequency, distribution and severity of bush fires damaging transmission lines and substations	

5.6 Long list of possible impacts and potential measures for infrastructure services

Table 13 Possible impacts and potential measures for infrastructure services (partly adapted from World bank's climate resilience guidelines for hydropower)

Project function	Climatic variable	Impacts on project function	Potential resilience measures in the domains: hazard mitigation, exposure reduction, increase of robustness, protection, and residual risk management
Seasonal and Weekly Storage	Change of river regime with increased floods and reduced base flow	Increase or decrease in storage requirement	Plan for revised optimal minimum operating level Lower the Power Intake Prepare provision for future dam raising and increased Full Supply Level Convert free overflow spillway into gated spillway Add fuse gates on free overflow spillway Bringing changes to operating rules such as revised reservoir level limits in provide an increased flood storage buffer Assessment of shifts in seasonality of rainfall and impact on hydropower and other water uses
Flood Control	Increased flood peak discharge	Increase of flood evacuation capacity	Revise monthly reservoir operating rule curves For concrete dams only, consider for extreme flood cases the option of dam crest overtopping with provisions of dam toe erosion protection Provision of enough free board for dams and sufficient spillway capacity Restricting the development of land within the zones susceptible to flooding Protect or remove vulnerable areas Establishing or revising flood forecasting and an Early Warning System Establishing strong water resources policy, stewardships, dam safety regulations, standards and guidelines
Sediment Control	Change in sediment load as a result of change in flow regime	Loss of active storage, clogging of intake structures, sediment erosion of turbines and/or greater generating outages	Increase temporary storage provision Increased and/or greater/or more efficient sediment removal facilities Sediment bypass tunnels/facilities (using surplus or/part of the water to carry the sediment past the intake areas) Use more resilient turbines Reservoir operation that considers sediment bypassing during floods Periodic mapping and monitoring of sediment accumulation and propagation in the reservoir and around intakes Proper location of intake structures considering sediment inflow and stability of reservoir rim Improving measures for protection of erosion and landslides

Table 13 Possible impacts and potential measures for infrastructure services (partly adapted from World bank's climate resilience guidelines for hydropower)

Project function	Climatic variable	Impacts on project function	Potential resilience measures in the domains: hazard mitigation, exposure reduction, increase of robustness, protection, and residual risk management
Flexible Multi-purpose Uses	General climate change concerns	Changes to water users	Carrying out studies directed at identifying the impacts of climate change upon the various users of water within a watershed and conflict resolution among competitive uses and users of water Modification to legal agreements between various governments, stake holders and other identities that have an impact upon the operation of the watershed Improvement to technologies and decision support tools that are used to coordinate the interaction of various hydro projects as well as the global operation of complexes involving several watersheds Better coordination of the planning and operation of the project with other water uses in the watershed with special emphasis on shared and transboundary rivers Promotion of educational efforts that are targeted with informing citizens of the impact of climate change, with the hope of finding adaptive measures that would compensate for the impacts and reduce negative impact on hydropower Modification to rules that have an influence upon ecological flows, recreation, irrigation, water supply and industrial water abstraction
Energy demand	Temperature	Daily demand levels (shift from evening to mid-day peak) and seasonal demand levels (change from winter to summer peak)	Reassess type of scheme (base load/peaking and runoff-river/storage) Reassess need to increase installed capacity Flexible operation considering fluctuations in demand and flow for instance, proper selection of number and type of turbines.
		System load factor changes (ratio of peak MW to average)	Reassess type of scheme (base load/peaking and runoff-river/storage)
		Impacts on other technologies (reduced thermal due to cooling water temperature/ availability, output of renewables)	Reassess type of scheme (base load/peaking and runoff-river/storage) Planning energy portfolio based on integrated planning of hydro with other renewables
		Increase in evapotranspiration rates and effect on water balance and water levels of reservoirs and regulated natural lakes	Improved modelling for evapotranspiration in the planning and operation of reservoirs including regulated natural lakes
	Precipitation and streamflow	Increased or decreased flow and hence energy	Developing or improving hydrological modelling and forecasting tools including the development and application of appropriate decision support methods to deal with extreme hydrological events (floods, droughts, dry spells, low flow, etc.) specifically, with a view towards energy production scheduling and modelling Reservoir planning and operation considering resilience to extreme floods and droughts

Table 13 Possible impacts and potential measures for infrastructure services (partly adapted from World bank's climate resilience guidelines for hydropower)

Project function	Climatic variable	Impacts on project function	Potential resilience measures in the domains: hazard mitigation, exposure reduction, increase of robustness, protection, and residual risk management
Grid support	General climate change concerns	Changed generation mix – replacement of fossil fuels by renewables	Increased focus for hydro on ancillary services for integration of other renewable generation Greater storage needed to back-up or balance intermittent generation Increased mechanical inertia to replace decommissioned thermal plant
		Increased behind-the meter generation	Dispatchability becoming more important as quantity of uncontrolled generation increases Improving power grid efficiency and regional integration, and regional power market
		Change from fossil fuels to electricity for space heating	New hydro generation needed to meet increasing energy demand
		Change from fossil fuels to electricity for transport	New hydro generation needed to meet increasing energy demand
Operation of hydropower assets		Poor operation of hydropower assets due to climate and hydrological conditions that are changed from the planning (baseline) data	Developing of improved technologies to evaluate the performance of projects and to identify ways of operating them under modified climatic conditions Creation of regulatory bodies that are mandated to develop and apply improved operating strategies Hiring experienced consultants for advice on the planning and operation of water infrastructure, capacity building and knowledge transfer Life-cycle, sustainability and reliability-based assessments for hydropower asset Increasing hydro-meteorological observations and monitoring to reduce hydrological uncertainties and risks

Climate event types

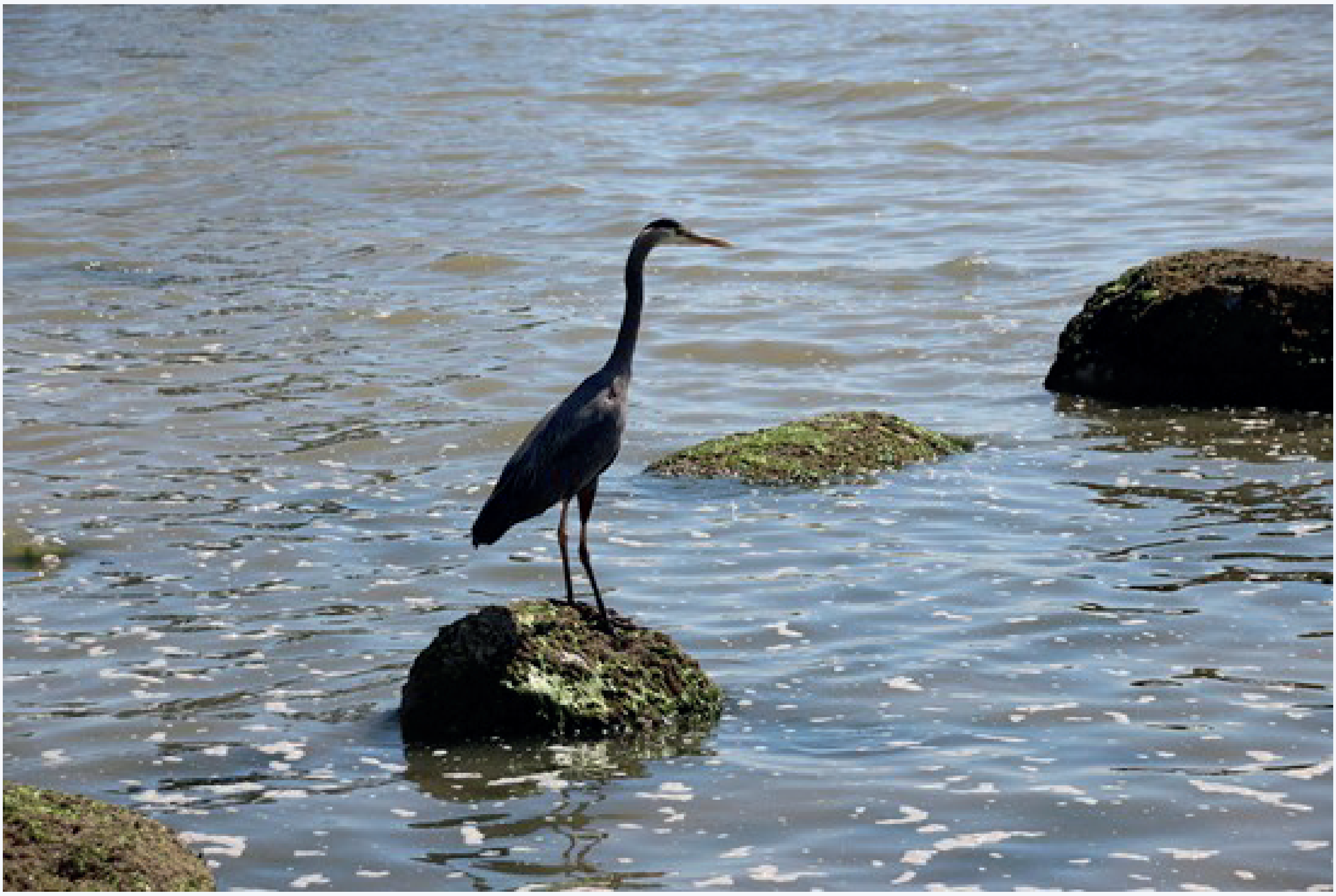
Climate event types	Secondary impact (link to event types)	Specifications / definitions; parameters	Parameter [unit]	Generic (final) impacts
Maritime related hazards	High mean sea level	Long-term (years) critically high mean sea levels	P: sea level U: [m]	
	High waves	Short-term events (minutes-hours) critically high waves (max. values)	P: wave height U: [m]	Inundation or critical objects
	Low mean sea level	Long-term (years) critically low mean sea levels	P: sea level U: [m]	
	Periods with low/no waves	Periods of low/no wave activity	P: wave height U: [m]	

Hydrological hazards (floods, low flows, water temperature, material concentrations)	Flood	High water levels	Short-term event (min.-days) with critically high-water levels (max. values)	P: water level U: [m]	
		High flow velocities	Short-term event (min.-days) with critically high flow velocities (max. values)	P: flow velocity U: [m/s]	
		High water volumes	Short-term event (min.-days) with critically high-water volumes (max. values)	P: discharge volume U: [m³/s]	Exceedance of water storages (supply)
	Period of high discharge		Period (weeks-months) with critically high mean water availability	P: discharge volume U: [m³/s]	
	Surface run-off		Short-term event (min.-days) with critically high-water volumes (max. values)	P: surface run-off U: [mm/time unit]	
	Low flow	Low water levels	Short-term event (days) with critically low water levels (min. values)	P: water level U: [m]	
		Low flow velocities	Short-term event (days) with critically low flow velocities (min. values)	P: flow velocity U: [m/s]	
		Low water volumes	Short-term event (days) with critically low water volumes (min. values)	P: discharge volume U: [m³/s]	Diminishing of water storages (supply)
	Period of low discharge		Period (months) of critically low mean water availability	P: discharge volume U: [m³/s]	
	High water temperatures		Short-term (days) occurrence of critically high water temperatures (max. values)	P: water T A: max value U: [°C]	
	Period of high water temperatures		Period (weeks-months) with critically high mean water temperatures	P: water T A: # days > threshold U: [°C]	
	Low water temperatures		Short-term (days) occurrence of critically low water temperatures (min. values)	P: water T A: min value U: [°C]	
	Period of low water temperatures		Period (weeks-months) with critically low mean water temperatures	P: water T A: # days < threshold U: [°C]	
	High concentration of substances (sediment, salt, pollutants, etc.)		Short-term (days) occurrence of critically high concentrations of substances in water bodies (max. values)		Change of ecosystem conditions (long-term changes in temp. and rain)
	Period of high concentration of substances		Period (weeks-months) with critically high mean concentration of substances in water bodies		
	Low concentration of substances (sediment, salt, pollutants, etc.)		Short-term (days) occurrence of low concentrations of substances in water bodies (min. values)		Change of ecosystem conditions (long-term changes in temp. and rain)
	Period of low concentration of substances		Onset of period (weeks-months) with critically low mean concentration of substances in water bodies		

Changes in soil/ rock climate conditions (ground temperature, saturation, drying, freezing, thawing)	Low ground temperatures				
	Period (season) of low ground temperatures				
	High ground temperatures				
	Period (season) of high ground temperatures				
	Wetted ground		Short-term event (hours-days) of critically high soil water		
	Period of wetted ground		Period (weeks-months) with critically high soil water		
	Drying ground		Short-term event (hours-days) of critically low soil water		
	Period of drying ground (drought)		Period (weeks-months) with critically low soil water		
Hazards related to moving soil/rock (landslides, erosion and deposition of material)	Mass movement	Mass wasting	Occurrence of sudden loss of rock or soil		
		Accumulation	Occurrence of sudden accumulation of rock or soil		
	Ground destabilization		Destabilization of ground surface		
	Erosion	Fluvial	Loss of material due to fluvial erosion		
		Surface run-off	Loss of material due to run-off erosion		
		Wind	Loss of material due to wind erosion		
		Ocean	Loss of material due to maritime erosion		
	Deposition	Fluvial	Deposition of material transported by rivers		
		Surface run-off	Deposition of material transported by surface run-off		
		Wind	Deposition of material transported by wind		
		Ocean	Deposition of material transported by the ocean		

6 ACRONYMS

BDPs	Basin Development Plans
CBA	Cost-benefit analyses
CCRA	Climate Change Risk Assessment
CRI	Climate Risk Institute
EbA	Ecosystem-based Approach
EFA	Economic and finance Analysis
EHCVs	Essential Hydroclimate Variables
EIRR	Internal rate of return
ENTRO	Eastern Nile Regional Technical Office
ENTRO	Eastern Nile Technical Program
ESIAs	Environmental and Social Impact Assessments
ESSA	ESSA Technologies Ltd.
FAO	Food and Agriculture Organization
GCM	General Circulation Models
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
ICLR	Institute for Catastrophic Loss Reduction
IDF	Intensity-Duration-Frequency
IESEs	Initial environmental and social examination
IKP	Integrated Knowledge Portal
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal rate of return
ISO	International Organization for Standardization
M&E	Monitoring and Evaluation
MDGS	Millennium Development Goals
MER	Monitoring, Evaluation and Reporting
NBI	Nile Basin Initiative
NBSF	The Nile Basin Sustainability Framework
NELIP	Nile Equatorial Lakes Investment Program
NELSAP	Nile Equatorial Lakes Subsidiary Action Program
NELSAP-CU	NELSAP Coordinating Unit
NGO	Non-Governmental Organisation
Nile-COM	Nile Council of Ministers
Nile-SEC	NBI Secretariat
NOAA	US National Oceanic and Atmospheric Administration
NPV	Net present value
PIEVC	Public Infrastructure Engineering Vulnerability Committee
PMF	Probable Maximum Flood
RCPs	Representative Concentration Pathways
SDGs	Sustainable Development Goals
SVP	Shared Vision Program
SWOT	Strengths, Weaknesses, Oportunities, Threats
UN	United Nations



ONE RIVER
ONE PEOPLE
ONE VISION

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NELSAP-CU