A METHODOLOGY FOR PRACTITIONERS

OVERARCHING GUIDE

INCORPORATING CLIMATE CHANGE ADAPTATION IN INFRASTRUCTURE PLANNING AND DESIGN

NOVEMBER 2015

COVER PHOTO

The inside cover photo shows an aerial view of Aqaba, Jordan. Desert cities, like Aquaba, are becoming more proactive in climate-proofing infrastructure (credit: USAID Jordan Water Reuse, Efficiency, and Conservation Project).

GLOBAL CLIMATE CHANGE, ADAPTATION, AND INFRASTRUCTURE ISSUES KNOWLEDGE MANAGEMENT SUPPORT

INCORPORATING CLIMATE CHANGE ADAPTATION IN INFRASTRUCTURE PLANNING AND DESIGN

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SUBMITTED TO:

USAID
FROM THE AMERICAN PEOPLE

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AECOM

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OVERARCHING GUIDE

CONTENTS

ACRONYMS

CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
CDCS	Country Development Cooperation Strategies
CIA	Central Intelligence Agency
FEWS NET	Famine Early Warning Systems Network
GCM	Global Climate Model
GRID	Global Resource Information Database
H&S	Health and Safety
IQC	Indefinite Quantity Contract
IPCC	Intergovernmental Panel on Climate Change
LoS	Level of Service
MCA	Multi-Criteria Analysis
MCC	Millennium Challenge Cooperation
NAPA	National Adaptation Programmes of Action
ND-GAIN	Notre Dame Global Adaptation Index
PRSP	Poverty Reduction Strategy Papers
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
WMO	World Meteorological Organization

KEY TERMS

ADAPTIVE CAPACITY, as it relates to infrastructure and built assets, describes the degree to which the physical elements of a system can absorb, withstand, or respond to climate change impacts without incurring damage.

CLIMATE is an expression of the composite weather conditions (e.g., temperature, precipitation, wind), including both statistical averages and the occurrence of extreme events, over a given period of time. The World Meteorological Organization (WMO) recommends a 30-year period to adequately describe the climate of a given area.

CLIMATE CHANGE refers to a statistically significant variation in climate data or patterns over a given period of time, due to either natural climate variability or as a result of human activity.

CLIMATE CHANGE ADAPTATION describes measures taken in response to actual or projected climate change in order to eliminate, minimize, or manage related impacts on people, infrastructure, and the environment.

CLIMATE CHANGE MITIGATION refers to actions that reduce the production of greenhouse gases that cause climate change. Although some adaptation strategies have mitigation co-benefits, they are not specifically referenced in this guide.

CLIMATE CHANGE IMPACTS on infrastructure are, for the purposes of this guide, the resulting influence of climate change effects on the structural form or function of an asset (e.g., the buckling of train tracks due to extreme heat).

CLIMATE CHANGE VARIABILITY is the short-term fluctuation in weather conditions, usually over a period of a year or a few decades.

CLIMATE DRIVER is the manifestation of a change in climatic conditions through one or more weather variables, such as a change in precipitation or sea level rise, to create an impact.

EXPOSURE refers to the extent to which a system comes into contact with a hazard.

LARGE-SCALE INFRASTRUCTURE SYSTEMS serve large populations and tend to be focused on urban areas.

RESILIENCE is the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through the preservation, restoration, or improvement of its basic structures and functions (IPCC, 2014).

RISK is the combined function of the likelihood that a hazard will occur and the resulting consequences.

SENSITIVITY is the degree to which a built, natural or human system is directly or indirectly affected by or responsive to changes in climate conditions or related impacts.

SMALL-SCALE INFRASTRUCTURE SYSTEMS serve smaller populations, ranging from villages to clusters or communities of households, and are often more relevant for rural areas.

VULNERABILITY is the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes. It is often defined as a combined function of exposure and sensitivity to the effects of climate change, minus the adaptive capacity of a system.

USAID Oti Burundi Visit

EXECUTIVE SUMMARY

Extreme weather events such as droughts, heat waves, dust storms, forest fires, floods, and landslides, which already disrupt the lives of millions each year, are expected to increase in frequency and intensity with climate change. The impact of these sudden events, in addition to the gradual change in climate effects over time, will put added stress on vital water, sanitation, flood management, transportation, and energy infrastructure. Responding to the impacts of climate change presents a major challenge for developing countries lacking adequate resources, and it is therefore an important focus of the United States Agency for International Development's (USAID) development assistance portfolio.

To help address this challenge, and consistent with Executive Order 13677 – Climate-Resilient International Development, USAID has developed the Global Climate Change, Adaptation, and Infrastructure Knowledge Management Support Project (a Task Order under the Architecture and Engineering Indefinite Quantity Contract or IQC) to articulate best practices in incorporating climate adaption in the planning and engineering design of USAID infrastructure activities.

Under this project, a suite of knowledge management products focused on climate resilient infrastructure design have been created. This document, entitled *Overarching Guide: A Methodology for Incorporating Climate Change Adaptation in Infrastructure Planning and Design*, is the first in this series. The overall objective of the guide is to support the consideration of climate change risks and adaptation in USAID infrastructure development activities. Serving as a technical companion volume to the USAID's *Climate Resilient Development: A Framework for Understanding and Addressing Climate Change*, it provides engineering and non-engineering development professionals with a comprehensive methodology to evaluate infrastructure vulnerability and select appropriate engineering design options to build resilience.

The knowledge management products created under this task order focus primarily on building the resilience of infrastructure through the application of a vulnerability, risk assessment and adaptation planning methodology. These products do not focus on mitigation of greenhouse gas emissions. An overview of potential impacts on typical infrastructure activities, adaptation responses, and strategies presented in this guide can help practitioners understand how the design of both new and existing structures can effectively deliver a particular level of service in a climate altered future. The methodology provides step-by-step guidance and checklists to follow in the assessment of infrastructure assets that are exposed to changing climatic conditions as well as in the selection of planning and management decisions.

The impacts of climate change will play an increasingly important role in defining the level of service, location, design, operation and maintenance, renewal, or retrofitting options, as well as eventual disposal of the asset. It is therefore vital that practitioners have effective tools and resources to develop and implement climate resilient solutions for existing and new infrastructure.

A SUITE OF CLIMATE ADAPTATION TOOLS

Accompanying this overarching guide are individual manuals or primers that focus on specific infrastructure sectors, such as flood management structures, potable water facilities, sanitation infrastructure, roadways, bridges, and irrigation systems. These manuals provide more detail on climate change impacts and specific adaptation responses and strategies related to each sector.

CLIMATE CHANGE IMPACTS AND RISKS TO INFRASTRUCTURE

Climate change will likely impact temperatures and precipitation levels, cause sea level rise, and increase the frequency and magnitude of storms and other extreme weather events (e.g., floods, droughts, heat waves), as well as shift future weather patterns. Specific climate impacts on infrastructure will be dependent upon the type of asset, its location, design, function, and condition. The methodology presented in this guide is a general process for assessing an asset's vulnerability and risk, while the individual sector-specific primers provide more in-depth information on impacts and engineering options to enable climate adaptation for different infrastructure types.

A STEPWISE APPROACH TO CLIMATE RESILIENT DESIGN

Climate change impacts on infrastructure should be considered at all levels of development planning. USAID's Climate Resilient Development Framework (2014) promotes the adoption of development strategies and infrastructure activities that integrate risk considerations in order to create more climate resilient infrastructure and thereby enhance cost effectiveness of interventions. These goals can be realized by following a five-step approach to: 1) establish the context; 2) conduct a vulnerability assessment; 3) conduct a risk assessment; 4) develop an adaptation strategy; and 5) implement activities in support of climate resilient infrastructure (addressed in Chapter 3).

ADAPTATION STRATEGIES AND RESPONSES

Responding to climate change impacts will require the selection of appropriate adaptation strategies. Effective strategies can be developed and selected based upon Climate Resilient Design Methodology described in Chapter 3 and will take into consideration a country's priorities, availability of resources, and temporal scale of the activities.

The diverse array of adaptation responses for enabling more climate resilient infrastructure design can be categorized under four types of strategic approach: 1) accommodate and maintain; 2) harden and protect; 3) relocate; and 4) accept or abandon. Each approach has advantages and disadvantages that are presented below in Table 1, and expanded upon in Chapter 4.

CASE STUDY

A climate change resilient infrastructure design case study is also provided to demonstrate the application of the methodology presented in this guide.

TABLE 1: STRATEGIC APPROACHES TO ADAPTATION

Strategic Approach		Advantages	Disadvantages
1	Accommodate and Maintain	• Less costly • More pragmatic and flexible, allows adjustment over time as more climate change data becomes available	• Requires monitoring, possibly frequent repairs, adjustments, or more rigorous operations • Necessitates design for more flexible or upgradeable structure
2	Harden and Protect	• Proactive • Straightforward to implement and justify	• More costly • Assumes reasonably accurate climate forecasts
3	Relocate	• Proactive	• More costly • Sub-optimal location may decrease period of performance or service
4	Accept or Abandon	• No extra up-front cost	• Proper communications needed to inform decision-makers and beneficiaries to expect lower performance or service

USAID JORDAN WATER REUSE, EFFICIENCY, AND CONSERVATION

CHAPTER I

INTRODUCTION

CLIMATE CHANGE AND INFRASTRUCTURE

There is broad scientific consensus that climate change will progressively impact communities throughout the world during the 21st Century and beyond. A rise in concentrations of greenhouse gas emissions in the atmosphere will contribute to an increase in global surface temperatures, which is likely to lead to changes in precipitation and temperature patterns and sea level rise. These changes will alter the frequency, intensity and distribution of natural hazards including storm surge, droughts, heat waves, dust storms, forest fires, floods, landslides, and other extreme weather events. The world's poor and marginalized populations often lack resources and engineering capacity to respond to impacts from climate stressors, and are therefore particularly vulnerable to climate-related impacts and damage. Consequently, the very projects and activities that are designed to help protect people from the impacts of climate change need to be more climate resilient.

Executive Order 13677 – Climate-Resilient International Development requires executive departments and agencies with international development programs to systematically factor in climate-resilience considerations into international development strategies, planning, programming, investments, and related funding decisions, including the planning for and management of overseas facilities.

The USAID Climate Change and Development Strategy 2012-2016 sets forth the Agency's commitment to addressing both climate change mitigation and the impact of climate change on economic growth of developing countries. The strategy is oriented towards making development more resilient to climate change and therefore more supportive to sustained economic growth.

The three primary objectives included in the strategy are:

1. Accelerate the transition to low emission development through investments in clean energy and sustainable landscapes;

2. Increase resilience of people, places, and livelihoods through investments in adaptation;

3. Strengthen development outcomes by integrating climate change in USAID programming, learning, policy, dialogues, and operations.

USAID's 2014 Climate Resilient Development Framework (Figure 1) focuses on how climate change can be mainstreamed into existing planning and decision-making processes to achieve the second priority to increase resilience. This current document on incorporating climate change considerations in infrastructure design supplements the Framework with additional tools that can be applied to various phases of USAID's infrastructure and engineering projects to enable climate resilient design (refer to Figure 2).

USAID's Framework for Understanding and Addressing Climate Change (2014) outlines a five-step process that focuses on how to mainstream climate change issues into planning and decision-making processes.

FIGURE 1: THE ESSENTIAL ELEMENTS IN USAID'S CLIMATE RESILIENT DEVELOPMENT FRAMEWORK

Scope	Establishes development context and focus
Assess	Enhances understanding about vulnerability
Design	Identifies, evaluates, and selects adaptation options
Implement and Manage	Puts adaptation into practice
Evaluate and Adjust	Tracks performance and impact

*Adapted from USAID's *Climate Resilient Development: A Framework for Understanding and Addressing Climate Change* (2014)

INCORPORATING CLIMATE CHANGE ADAPTATION IN INFRASTRUCTURE PLANNING AND DESIGN

This guidance document will help practitioners answer the following questions about specific infrastructure projects:

- What climate change trends are projected for the region and will the program be exposed to those impacts?
- Is the infrastructure asset sensitive to the climate change impacts expected for the region, and if so, to what degree?
- Do the climate change impacts on the infrastructure asset create low, medium, or high risk?
- What adaptation strategies might be appropriate for reducing the risk to the project and what factors are important in selecting appropriate strategies?
- What approaches should be used to evaluate and select appropriate adaptation strategies to implement?

OPPORTUNITIES TO CLIMATE PROOF INFRASTRUCTURE AND MANAGE RISK

Risks to infrastructure are varied, and result in a wide range of impacts across all sectors. They can range from increased roadway repair and maintenance needs, resulting from more frequent flooding and extreme rain events; possible inundation of valuable coastal infrastructure, such as road networks from sea level rise; overheating of electricity infrastructure from increased frequency and intensity of heat waves; reduction in available water resources such as rainwater, surface water and groundwater.

Regions around the world differ in the challenges they face from climate change impacts, thereby requiring that a customized approach to evaluating risks based on location-specific data and information be employed. For example, although sea levels are generally rising worldwide, they are doing so at different rates, with impacts compounded or reduced due to adjacent land masses that may also be rising or sinking at the same time. Some densely populated coastal areas will become uninhabitable with sea level rise, thereby putting strain on adjacent inland regions.

FIGURE 2. OPPORTUNITIES FOR CLIMATE CHANGE CONSIDERATIONS IN THE INFRASTRUCTURE DEVELOPMENT AND MANAGEMENT CYCLE

Unsealed roads in Mali will not able to cope with the impacts of climate change that can wash them away during extreme weather events and flooding.

USAID ADAPT

Due to the sensitivity of infrastructure to climate change impacts, adaptation is critical. Development of new infrastructure and rehabilitation of existing facilities must be customized with site specific climate resiliency in mind, beginning with the early phases of engineering design and infrastructure planning. Past and future climate conditions should be considered when planning and managing all aspects of infrastructure activities, including concept development, asset planning and design, construction, operations, maintenance, monitoring, renewal, and disposal.

Taking a proactive approach in planning and engineering design is far more cost-effective than adopting a reactive approach. Planning for climate change impacts will, in most cases, be less costly than having to repair or discard a damaged or irrelevant structure. These considerations require a process of data gathering, analysis, and evaluation to develop and engineer appropriate adaptation measures. This process will enable communities to build, operate, and protect infrastructure assets from climate impacts, thereby enabling continued climate resiliency.

HOW TO USE THIS GUIDE

This overarching guide provides information that USAID and implementing partners can use to reduce the vulnerability of infrastructure investments to climate change impacts in partner countries. It is not an exhaustive technical resource on climate change adaptation or engineering design. Rather, it is intended to enable managers to ask the right questions and assess infrastructure vulnerability in order to make decisions on appropriate measures to improve climate resilience in all stages of the infrastructure project life cycle.

Some of USAID's infrastructure investments are made through jointly implemented programs with other development partners or counterparts, with targeted budget support of projects co-financed through development banks and other donors. This guide may be used where no process yet exists, serving as a framework for the development partner or counterpart to make their own infrastructure assessment.

CHAPTER 2

CLIMATE IMPACTS AND RISKS

CLIMATE RELATED DRIVERS OF IMPACTS

Infrastructure encompasses a variety of interdependent built and non-built networks and structures. Power stations provide energy to help information technology and telecommunication systems function, which in turn operate water management systems. Roadways and bridges can provide an intricate network needed to support the operation of many facilities, such as sanitation and health infrastructure. The development of new infrastructure and the renewal and maintenance of existing assets will increasingly be impacted by climate change. Consequently, it will be critical that practitioners understand how natural hazards and the changing climate will likely impact infrastructure assets and services in order to assess risks and make informed decisions regarding asset design, operation and maintenance.

The primary climate drivers referenced in this guide are identified below. Icons are provided for each climate driver and are used as visual aids throughout this guide. Additional natural hazards that are not explored in this guide but may affect infrastructure include tsunamis, earthquakes, volcanic eruptions, landslides and rockfalls.

KEY CONSIDERATIONS IN IDENTIFYING IMPACTS

Climate change is likely to impact infrastructure assets through modification in the pattern of extreme climatic events, which includes storms and storm surge, forest fires, floods, and drought; or through gradual changes in seasonal or annual patterns of temperature, solar radiation, precipitation, and sea level rise. Evaluating the impact of climate change and consequent risk to infrastructure requires addressing two overarching concerns – the timeframe for the asset's productive lifespan and required capital costs. While engineering design always considers some measure of extreme weather conditions, it is important to consider a temporal scale that is appropriate to the anticipated life of the asset as well as the cost-effectiveness of climate resilience options.

Temporal scale of the planned infrastructure asset will affect the degree to which risk is addressed. For example, if an infrastructure asset is designed as a short-term or temporary solution or if it is a relatively small project, it may be unnecessary to fully assess long-term climate related risks. If it is a large-scale project or an asset that is expected to function for the long-term, a longer timeframe would need to be considered.

CLIMATE DRIVERS

EXTREME HEAT/ HEATWAVES: Extreme temperatures are location specific. Heatwaves are prolonged periods of excessively hot weather. Likely increase in extreme air temperature and heatwaves in most areas.

DRYING TREND/ DROUGHT: A prolonged dry period in a natural climate cycle which results in a shortage of water. Likely increase in drought conditions in some areas through a warming of air temperature and decrease in precipitation.

EXTREME PRECIPITATION/ FLOODING: Extreme precipitation events are location specific and can cause flooding when downpours exceed the capacity of river or urban drainage systems. Uncertain climate projections, expected to intensify in some areas.

STORM SURGE: The difference between the actual water level under the influence of a meteorological disturbance (storm tide) and the level which would have been attained in the absence of the meteorological disturbance (i.e. astronomical tide). Sea level rise exacerbate storm surge height.

SEA LEVEL RISE: Anticipated sea level changes due to the greenhouse effect and associated global warming. Leads to changes in erosion and accretion, long term inundation, exacerbate storm surge and tsunami height.

DAMAGING STORMS (WIND, LIGHTNING): Severe weather systems involving damaging winds and heavy rainfall downpour, including tornados, hailstorms, tropical cyclones and hurricanes. Uncertain climate projections.

WILDFIRE: A massive and devastating fire which destroys forests, grasslands and crops, kills livestock and wild animals, damages or destroys settlements and puts lives of inhabitants at risk. Uncertain climate projections.

KEY CONSIDERATIONS

In developing countries, climate adaptation measures will be required to reduce the costs and disruption caused by climate change. Keeping in mind the key aspects noted above, it will also be important when designing or rehabilitating infrastructure systems to follow certain principles that will help create greater resiliency by planning not just for the current climate, but for the climate scenario projected for the entire design life of the infrastructure asset.

Impacts are a function of current and future climate variability, location, asset design life, function, and condition. Many characteristics of the asset and its location influence the likelihood and extent of climate impacts. These characteristics must be considered when establishing the context for the climate change risk and vulnerability assessment. Questions about the condition of the existing asset base (Has it been maintained? What is its current failure rate?) are important to evaluate as part of a thorough and comprehensive assessment.

Climate change can cause direct damage to assets and indirect impacts including loss of service. Changes in the pattern of extreme events can directly impact the physical integrity of built structures in a variety of ways, causing loss of service. Gradual changes can also exert impacts, such as in the degradation of materials due to increased exposure to erosion or salinity from sea level rise.

Climate change may affect the availability of resources associated with the asset. Some assets may not be directly affected by climate change, while the resource they depend upon might be impacted, thereby rendering associated infrastructure redundant or over-designed. For example, water pipes might be physically unaffected by a drought, but if water resources are insufficient, the water distribution network may not be utilized at its full design capacity.

Current infrastructure design is based on historical data and experience. Most existing infrastructure assets were designed based on historical climate data, such as average rainfall and runoff in an area, or historic flood events. However, the pace of climate change means that historic data may no longer be relevant for long-term infrastructure performance. Climate change may cause shorter life spans for assets or require early rehabilitation as infrastructure degradation accelerates.

Climate variability or increased frequency of extreme events may mean that infrastructure is no longer optimally designed for even short-term purposes. To illustrate, it is likely to be preferable to design a stormwater conveyance system to a higher standard than current design guidance in anticipation of future extreme flood events. These situations are often exacerbated in less developed countries where design standards and climate project data may be out of date or nonexistent.

For new assets, both the location of the asset and the level of service should take climate change into consideration. Asset location is particularly relevant in coastal areas and floodplains. The capability of the asset to perform at full capacity may be impacted by changes in the environment or the resources (such as water) that it requires. Service demand may also change, such as increased power use for air conditioning and cooling as average air temperatures gradually rise over time.

Uncertainty in climate projections should not prevent them from being considered in design. When considering the design of an asset, the question of how high or how big is critical and not easily answered with available climate projections. To help overcome this, consider the implications of failure. If it is critical that there be no interruption to service then consider the upper bounds of the possible risk (i.e. worst case climate projections) would be prudent. Alternatively, consideration should be given to the marginal costs and benefits of a design decision. Sensitivity testing of a design's relative costs and benefits may show that the risk management benefits from a larger pipe, or higher asset, may significantly out-weigh the marginal cost.

Climate related changes in demand for services can shift. Warmer temperatures and more frequent heat waves can lead to increased demand for water. Demographic shifts, such as those caused by the relocation of coastal communities affected by flooding and sea level rise, may affect demand for infrastructure services.

Indirect impacts and cascading consequences can be more difficult to identify than direct impacts, but they should nevertheless be considered. As an example, inadequate power distribution services during an extreme climate event can impact access to potable water in systems using pumps, thereby exacerbating access which may already be strained during a drought. Cascading consequences might occur if, for example, a bridge designed for increased flood events is inaccessible because associated access roads are flooded due to sea level rise and storm surge.

ILLUSTRATIVE CLIMATE CHANGE IMPACTS AND RISKS

The connection between infrastructure planning and climate change adaptation are strong. Practitioners need to understand the climate change impacts on built assets and the resulting risks in order to make appropriate engineering design decisions. The following tables summarize impacts posed by a range of climate stressors and consequent risks to infrastructure related to water supply, sanitation and wastewater treatment, solid waste, flood management, renewable and non-renewable energy, vertical structures, transportation, and information and communication. Appropriate adaptation strategies with examples of specific measures to mitigate risks and impacts are provided in Chapter 4.

The examples of potential impacts and consequent risks laid out in Tables 2-11 are intended to provide neither an exhaustive catalogue of all the possible impacts nor all adaptation options for each infrastructure sector. What these tables do present is an illustration of the range of potential impacts to inform further analysis and adaptation planning.

TABLE 2: ENERGY INFRASTRUCTURE - NON-RENEWABLE (COAL, OIL, AND GAS), ELECTRICITY TRANSMISSION, DISTRIBUTION, AND STORAGE

Climate Drivers	Impacts and Consequent Risks
Coal, Oil, and Gas Extraction	
Increased number and intensity of tropical storms	• More intense and frequent tropical storms increase the potential for damage to offshore oil and gas platforms, pipelines and oil or gas tanker wharves
Increased frequency of extreme precipitation events and flooding	• Increased likelihood of flooding in mines and environmental pollution
Coal, Oil, and Gas Distribution and Storage	
Increased variability in wet/dry spells	• Ground movements induced by falling groundwater table or variation in ground moisture content may result in damage to gas and oil pipeline foundations
Power Generation (Coal, Oil, Gas)	
Increased variability in wet/dry spells	• Decreased availability of water for the cooling of coal-fired power and gas-fired power stations during power generation
Electricity Transmission and Distribution	
Increased number of hot days and heat wave events	• During very hot days, the likelihood of high or low voltage faults increase as well as the likelihood of fatal equipment failure • High temperatures reduce transmission line conductivity, thereby reducing efficiency
Increased frequency and intensity of extreme wind	• Increase in storms may impact high or low voltage faults
Increased frequency of dry spells and droughts	• Increased dust builds up on insulators which can cause arcing and subsequent interruptions

TABLE 3: ENERGY INFRASTRUCTURE - RENEWABLE

Climate Drivers	Impacts and Consequent Risks
Solar	
Change in cloud cover and solar radiation levels	• Reduction in productivity or efficiency of renewable energy generation infrastructure
Wind	
Increased intensity and frequency in tropical storms	• Increased likelihood of damage to wind turbines
Changes in wind patterns (duration and direction)	• Reduction in productivity or efficiency of renewable energy generation infrastructure • Change in the viable location of renewable energy generation infrastructure
Hydro	
Changes in snow cover duration and height, glacier volume, and seasonal and annual water availability	• Reduced availability and reliability of water for hydro-power during certain periods of the year
Changes in rivers' sediment load; increased erosion and sedimentation	• Maintenance issues due to increased sedimentation in water used for power generation
Biofuel	
Reduced annual rainfall; increased temperatures; increased potential for wild fires	• Increased conflict over water use; priority may be given to food crops over biofuel crops • Increased potential of crop damage from wild fires
Marine	
Changes in wave patterns (duration and direction)	• Either increased or decreased potential for wave power generation

TABLE 4: ENVIRONMENTAL ASSETS

Climate Drivers	Impacts and Consequent Risks
Reservoirs and Storage	
Reduced annual rainfall; increased temperature; increased potential for wildfires	• Decreased viability of species and ecosystems, which may affect management techniques • Increased risk of biodiversity loss from more intense or frequent fires
Increased coastal inundation and frequency and/ or intensity of flooding from storm surge; sea level rise	• Coastal erosion, landslides and increased salinity affecting vegetation cover and viability of species and ecosystems
Increase in extreme wind, storms and rainfall intensity	• Damage to vegetation potentially creating wind-blown hazards that may affect infrastructure or cause injury

Small-scale sanitation landfills that lack protection from extreme weather events are highly susceptible to impacts from climate change.

AECOM

TABLE 5: FLOOD MANAGEMENT INFRASTRUCTURE	
Climate Drivers	**Impacts and Consequent Risks**
Coastal Flood Containment Structures (Embankments, Seawalls, Spurs)	
  Increased coastal inundation and frequency and/or intensity of flooding from storm events; sea level rise	• Submersion or destruction of infrastructure, leading to increased flooding of coastal buildings and assets, potential loss of life • Change in distribution of storm events may affect may result in wider areas of impact or impact on areas without sea wall protection
River Flood Containment Structures (Embankments, Levees, Dikes, Diversion Channels)	
 Increased frequency of extreme precipitation events and flooding	• Higher precipitation can generate higher flows and increase erosion of structures and riverbanks, as well as riverbed instability, thereby lowering flood protection • More intense precipitation events generate larger floods which can submerge or destroy structures, leading to increased damages, and potential loss of life in floodplains and river valleys
River Dams (Large and Medium, and Ice Dams)	
 Increased frequency of extreme precipitation events and flooding	• Higher precipitation can increase upstream erosion and reservoir sedimentation, leading to reduced storage and flood protection • More intense precipitation events generate larger floods which can exceed storage capacity, or submerge or destroy structures, leading to increased damages, and potential loss of life in floodplains and river valleys
  Change in temperature and precipitation patterns	• Failure of ice-dammed lakes generates large floods which can submerge or destroy downstream structures, leading to increased damages, and potential loss of life
Urban Stormwater Networks	
 Increased frequency of extreme precipitation events and flooding	• More intense precipitation events generate larger floods which may overflow structures, leading to increased damages and potential loss of life, notably in dense urban areas

TABLE 6: INFORMATION AND COMMUNICATIONS TECHNOLOGY INFRASTRUCTURE

Climate Drivers	Impacts and Consequent Risks
Fixed Lines	
Increased solar radiation	• Damage to cables
Increased frequency and intensity of tropical storms	• Increased damage to above ground structures
Mobile Telecommunication Towers	
Increased frequency and intensity of wind gusts, electrical storms, and tropical storms	• Damage to mobile telecommunications towers leading to increased maintenance and repair costs • Impacts to one single network are likely to have cascading consequences that affect other linked networks, such as traffic signal centers
Increased variability in wet/dry spells	• Decline in stability of tower structures and foundations from changes in soil moisture or flooding • Impacts to ground movements linked to wet and dry season cycles leading to land slides are likely to have an impact on towers
Exchanges (Building)	
Increased variation in wet/dry spells	• Damage to building structures and stability can result in significant safety risks, disruption in access and potential loss of asset
Traffic Signal Centers (Roads, Railways, Ports, and Airports)	
Increased frequency of extreme precipitation events and flooding	• Increased frequency or intensity of flooding events could damage exchange buildings and transmission lines

TABLE 7: SOLID WASTE INFRASTRUCTURE

Climate Drivers	Impacts and Consequent Risks
Landfills and Related Infrastructure	
Increased frequency of extreme precipitation events and flooding combined with sea level	• Increased likelihood of flooding in low-lying landfills and increased leachate, causing contamination of local water supplies
Increased temperatures and risk of fire	• Changes in decomposition rates of waste at landfills and stockpiles • Increased risk of fire
Higher intensity storm and wind events	• Increased dispersal of waste and damage to waste facilities may require replacement, rebuilding, or covering, thereby increasing maintenance and costs

TABLE 8: TRANSPORTATION INFRASTRUCTURE

Climate Drivers	Impacts and Consequent Risks
Roads	
Increase in extreme temperature, rainfall, wind, cyclones, and solar radiation	• Damage to roads from landslides, flooding and ground movement can block access to essential emergency services, food supplies and, in the longer term, disturb access to markets and other economic opportunities • Higher temperatures and solar radiation can increase the rate of degradation of materials leading to higher maintenance costs
Increased frequency of extreme precipitation events and flooding	• Most stormwater drainage systems have been designed based on historic precipitation data. It is possible that they will not withstand more intense and frequent events, thereby leading to roads washouts and flooding of assets
Railways	
Increased solar radiation, intensity of extreme winds events and high temperatures	• Buckling of rails may cause disruption to services and blocked access to homes and businesses • Exposure to higher temperatures could lead to increased maintenance, repairs, and replacement
Reduced annual rainfall; increased temperatures; increased potential for wild fires	• Disruption of service and damage to assets

TABLE 8: TRANSPORTATION INFRASTRUCTURE (continued)

Climate Drivers	Impacts and Consequent Risks
Bridges	
Increased variation in wet/dry spell	• Damage to bridge structures and stability can result in significant safety risks, disruption in access and potential loss of asset
Tunnels	
Increased variation in wet/dry spells	• Damage to soil foundations supporting tunnels
Airports	
Increase in extreme wind, storms and rainfall intensity	• Changes in climate effects can increase weather delays and grounding of planes. Low lying coastal airports may be damaged by increased height of storm surge. These impacts have the potential to reduce the provision of essential and emergency aid supplies to remote communities
Increased variation in wet / dry spells, solar radiation; increased frequency in high temperatures	• Degradation of the quality of sealed and unsealed runway surfaces, including damage to foundations, leading to grounding of planes and other risks described above
Ports and Maritime Facilities	
Increased cyclone intensity and frequency; increased temperatures	• Extreme wave action can lead to port closures and reduction in supply of essential and emergency goods and services, including development aid • Damage from more frequent intense cyclones may lead to increased maintenance, repairs, and replacement assistance
Sea level rise and ocean acidification	• Sea level rise exposes asset components that have not been designed for saltwater contact and therefore likely to result in increased corrosion • Ocean acidification is likely to increase corrosion rates of port structures • Height of wharfs, cranes, and jetties may become inadequate for ships as the sea level rises

TABLE 9: VERTICAL STRUCTURES

Climate Drivers	Impacts and Consequent Risks
All Buildings (Public and Residential Use, Settlements, and Cultural Heritage)	
Increased temperature and number of hot days and heat wave events	• Warmer temperatures may cause increased demand for energy to cool buildings, which could overwhelm the grid and lead to outages; at the same time, there would be a decrease in the electricity consumption for heating needs in colder climates if average annual winter temperatures increase
Sea level rise	• Direct exposure of coastal buildings to sea level rise, resulting in increased coastal erosion, sedimentation and salinity
Change in the frequency and intensity of tropical cyclone activity and associated storm surge	• Increased exposure of coastal structures to winds and flooding damage (such as through coastal flooding or heavy rainfall events) • Loss of power for cooling, heating and lighting
Increased variability in wet/dry spells	• Increased damage to building foundations due to moisture-related ground movements, especially in regions with clay soils; damage to buildings and foundations due to flooding
Urban Facilities (Public and Residential Use, Settlements, and Cultural Heritage)	
Increased variability of extreme events	• Increased damage to structures and related services including street lights • Increased exposure of socially and economically vulnerable populations to extreme weather events (e.g. those in extreme poverty, people living in informal settlements and squatters)

Creating climate resilient infrastructure includes understanding the exposure of the asset and its sensitivity to climate stressors. When rehabilitating or constructing new buildings it will be important to take these stressors into considerations during design and planning stages.

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TABLE 10: WASTEWATER AND SANITATION INFRASTRUCTURE

Climate Drivers	Impacts and Consequent Risks
Small-scale Sanitation	
Increased frequency of extreme precipitation events and flooding	• Pit latrines, the most common rural sanitation approach, are vulnerable to flooding, and can contribute to environmental contamination when flooded • Septic tanks and latrines can be inundated or filled with silt in flooding situations, and underground tanks are susceptible to soil movements when surrounding soils are saturated • Latrine superstructures can be damaged or washed away
Sea level rise; storm surge	• For septic tanks and latrines within reach of sea level rise and associated rising groundwater levels, underground structures are susceptible to ground movements and flotation, and pits could collapse or become inundated • Contamination of nearby water supplies from salt water or contaminated groundwater is also an increasing concern
Increased variability in wet/dry spells	• Possible increased degradation and failure of latrines and septic systems can lead to an increased need in rate of replacement • Water restrictions reduce wastewater flows leading to increased incidence of blockages and unhygienic conditions • Long-term declines in water availability could decrease the potential for groundwater contamination from septic tanks or latrines
Large-scale Sanitation	
Increased frequency of extreme precipitation events and flooding	• More frequent and intense flooding could increase the likelihood of sewer network overload, resulting in possible overflow to the drainage network or flooding of wastewater treatment plants and creates potential for contamination of downstream waterways and bays • Wastewater treatment plants (which tend to be at lower elevation points) may become frequently flooded, thus generating downstream pollution
Sea level rise; storm surge	• Trunk sewers located at or near sea level may be subject to increased tidal gradient, groundwater infiltration, and overload, resulting in possible reduction in capacity and increased risk of environmental spills during high rainfall events and high tides • Trunk sewers that discharge into the sea may experience backflow • Treatment works located near sea level to take advantage of gravity driven flow may need to be relocated
Increased variability in wet / dry spells	• Possible increased degradation and failure of sewer pipes leading to increased rate of replacement • Water restrictions can reduce wastewater flows leading to increased incidence of sewer blockages
Increased drought and decreased ground moisture content	• Long-term declines in surface water availability could decrease the viability of waterborne sewerage and decrease the ability of surface water sources to dilute and attenuate pollutants

TABLE 11: WATER SUPPLY INFRASTRUCTURE

Climate Drivers	Impacts and Consequent Risks
Extraction and Conveyance Structures	
More frequent drought conditions	• Decreased availability of surface water resources, increased need for additional groundwater sources (or deeper wells and increased pumping costs to reach deeper groundwater tables)
Higher intensity storms	• Physical damage to structures, potential flooding
Sea level rise	• Saline intrusion into freshwater supplies • Corrosion of intake or conveyance structures
Treatment Structures	
More frequent drought conditions	• Decreased raw water quality due to diminished runoff and flows, and thus less dilution of pollutants • Increased treatment costs
Higher intensity storms	• Physical damage to structures; potential flooding • Lower treatment effectiveness due to turbidity
Sea level rise	• Potential inundation
Increased surface water temperature	• Decline in raw water quality due to algal blooms and increased treatment requirements

Climate change is likely to bring more frequent and intense weather which may result in massive flooding, causing roads to be washed away or made inaccessible.

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TABLE 11: WATER SUPPLY INFRASTRUCTURE (continued)	
Climate Drivers	**Impacts and Consequent Risks**
Reservoirs and Storage	
More frequent drought conditions, increased evaporation	• Decreased availability of water resources • Need for increased inter-annual storage capacity
Higher intensity storms	• Additional storage facilities needed to capture water during shorter, higher intensity storms
Increased frequency and intensity of wildfires	• Reduced recharge of water storages associated with vegetation regrowth • Reduced water quality on storages associated with increased particulate matter from fires in catchments
Distribution	
More frequent drought conditions	• Decreased supply and thus intermittent or low pressure delivery, with increased risk of contamination from wastewater intrusion
Higher intensity storms	• Need for increased inter-annual storage capacity • Physical damage to pipes, flooding and contamination
Irrigation Demand	
More frequent drought conditions. increased, evapotranspiration and reduced soil moisture	• Irrigation systems designed using historical precipitation data are likely to be unsustainable for future projections of reduced precipitation • Increased demand for urban or industrial water supplies may result in reduced availability of water for irrigation


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CHAPTER 3

A CLIMATE RESILIENT INFRASTRUCTURE METHODOLOGY

A METHODOLOGY TO ENABLE CLIMATE RESILIENT PLANNING AND DESIGN

The incorporation of climate change adaptation principles into infrastructure planning, design or renewal does not require a major process change. Instead the following approach stipulates an integration of climate change considerations in each phase of project implementation by:

- Taking into consideration future climate conditions (along with past and current climate conditions); or
- Considering uncertainty in the review and use of climate data through sensitivity testing and adjusting the design (for example through a greater safety margin) or, at a minimum, adjusting the performance or service expectations of the designed structures.

Examples of alterations in engineering design could include:

- Rehabilitating a stormwater network for greater capacity as extreme precipitation events are expected to increase in the future;
- Designing foundations of a new seawall so that it can be heightened in the future in response to sea level rise (e.g. flexible adaptation);
- Relocating a powerplant further from the coast in order to prevent flooding due to sea level rise and coastal storm surge;
- Building a new bridge at a higher elevation if the existing structure is frequently submerged and damaged by river flooding (the old bridge would be dismantled after construction).

STEPWISE APPROACH FOR CLIMATE RESILIENT INFRASTRUCTURE PLANNING AND DESIGN

The management of climate change risks in USAID infrastructure activities can be facilitated by following a five-step process:

5 STEP PROCESS

1	Establishing the Context
2	Vulnerability Assessment
3	Risk Assessment
4	Development of Adaptation Strategies
5	Implementation

Collectively, these steps establish a climate resilient design methodology to be used when determining appropriate engineering design actions for more climate resilient structures.

This process will help establish whether or not an existing or future infrastructure asset is vulnerable and at risk from climate change impacts. Tools, in the form of checklists, worksheets, or matrices, can support practitioners in undertaking these steps and are provided in this chapter.

INTEGRATING THIS METHODOLOGY IN INFRASTRUCTURE DEVELOPMENT ACTIVITIES

This chapter provides a step-wise methodology to enable practitioners to include climate change considerations in the design of new structures or the evaluation of existing ones (see Figure 3).

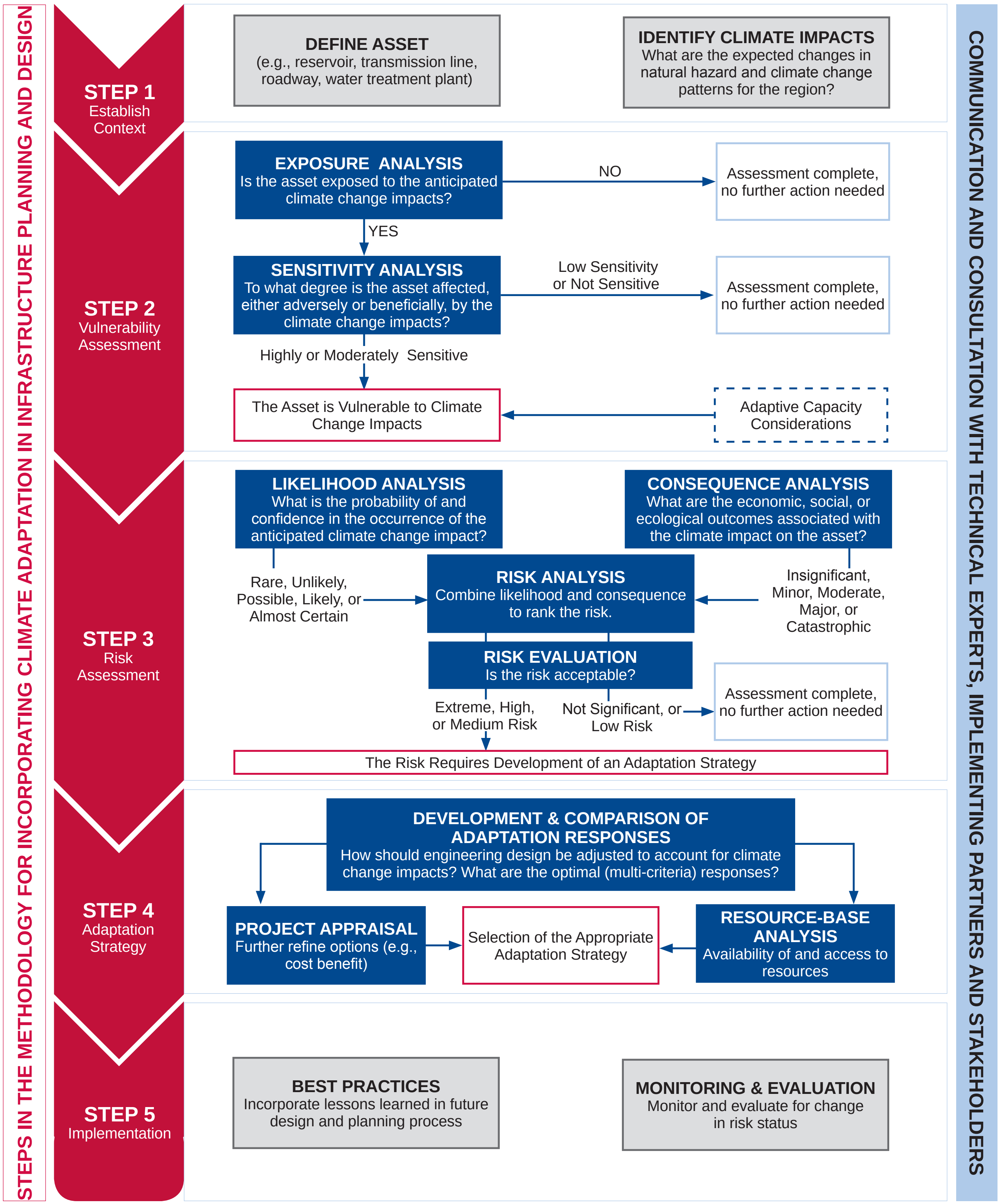
- **STEP 1** establishes the context of the assessment defining the Asset and the climate impacts that will be the focus of the assessment.
- **STEP 2** considers the vulnerability (exposure, sensitivity, and adaptive capacity) of the assets screening those that require more detailed analysis.
- **STEP 3** identifies, analyzes and evaluates the subsequent risks (combining likelihood with consequences).
- **STEP 4** develops adaptation strategies to address the most significant risks.
- **STEP 5** guides the implementation, monitoring and evaluation of adaptation solutions.

In applying the methodology, the majority of the effort is focused on Steps 3 and 4. Risk assessment and adaptation to climate change impacts should be part of a multi-criteria decision-making process (along with other technical, socio-cultural, environmental, economic, and financial factors) that reviews solutions and options during engineering planning and design. While the capital costs of creating infrastructure assets that are more resilient to climate change impacts may guide the adaptation strategy selection and design, a pro-active approach when possible and affordable is often more cost-effective than being reactive. It will ultimately be more economical to build stronger and better located assets than to rebuild or repair structures following a disastrous event, in addition to other costs such as healthcare and clean-up that may result from failure of an asset.

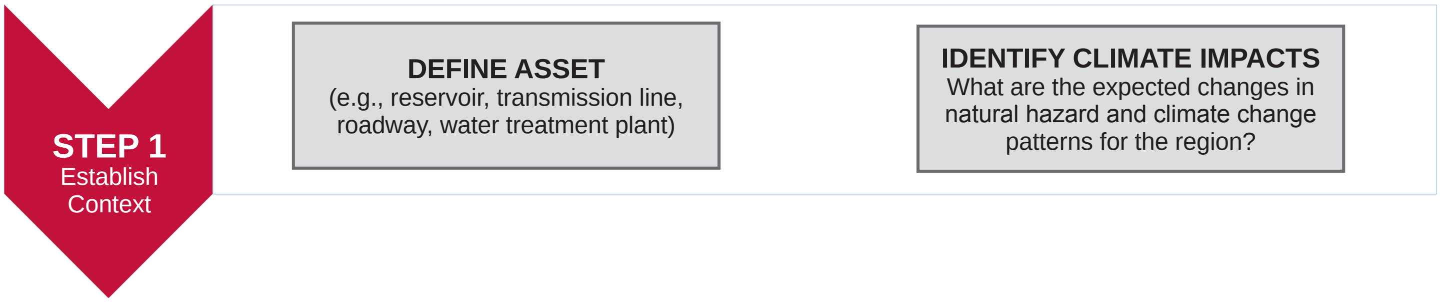
If a risk management process is already in place for infrastructure activities, the following framework can be used to assess the adequacy or identify gaps in the process. If there is no existing risk management process in place, this step-wise approach can be used to establish such a process.

A rural road improvement project is undertaken in Lao PDR. Integrating climate considerations in the engineering design will create a more resilient and safer means of travel.

FIGURE 3: CLIMATE RESILIENT INFRASTRUCTURE PLANNING AND DESIGN METHODOLOGY



STEP 1: ESTABLISHING THE CONTEXT



The first step in the overall approach is to define the service to be delivered by the infrastructure activity in the face of future climate change. In order to effectively manage infrastructure activities, it is important to understand the larger context in which the asset will operate to support development activities.

DEFINING INFRASTRUCTURE OBJECTIVES

A clear scope needs to be defined to effectively focus the assessment. The following questions can guide the scope development: What are the critical services that are being targeted (e.g. provision of water)? What are the assets and operations that support the delivery of those services (e.g. distribution infrastructure)?

When considering the services provided by an asset, it is important to review the likely future per capita service utilization. Understanding projected use can assist in determining if any changes to the target level of service may be required. Climate change can represent one of a number of influences that may affect demand for a particular service or asset, and practitioners should therefore assess the potential for changes in demand as a result of climate change risks. For example, climate change induced drought may cause a gradual shift in population over time towards a specific water source or away from an area at risk due to sea level rise, and anticipated demand will rise or fall accordingly. Consideration should also be given to the broader system that the assets are integrated with. Once the scope of the assets is defined, information is needed about the assets to inform the later stages of the assessment. Typically an inventory or database is developed that contains information on each asset's criticality, function, condition, location, design and interdependences. This information may be sourced from existing asset management systems or operational staff. Site visits or physical surveys may also support this task.

UNDERSTANDING AND IDENTIFYING CLIMATE AND NON-CLIMATE STRESSORS

Gathering data and information via research will also help practitioners understand current hazards, how they may be affected by climate change, and identify relevant internal and external factors that are within or outside the control of the project team or organization.

Internal factors include objectives and criteria governing investment decisions, engineering specifications, or service delivery targets. External factors include socio-economic (financial resources, economic activities, culture and traditions, education, and socio-demographic conditions); biophysical aspects (biodiversity, geomorphology, hydrology, and soils); and institutional arrangements (governance, regulations, and stakeholder relationships among public, private, and voluntary sectors).

Most of these factors will be reviewed as part of typical planning infrastructure development activities. The additional element that must be integrated involves climate science modeling for the region to understand what the likely changes in climate variables such as rainfall patterns, extreme temperature, or storm events might be. For low lying coastal projects, projected sea level rise and storm surge must also be reviewed.

SOURCING CLIMATE DATA

USAID development projects are undertaken in a variety of geographic settings and country contexts involving floodplains, coastal atolls, mountainous and arid regions. When evaluating climate impacts and risks to infrastructure assets, understanding the context by collecting climate data and projected trends for specific geographic locations will be a critical first step. In many developing country settings, detailed climate observations and projections may be scattered, inaccurate, incomplete, or not available. Lack of weather stations, difficulties in terrain, and inaccuracies from data collection (i.e., human error) are all factors that can create uncertainty. Practitioners can respond by making conservative estimates based on available data and source data at the regional and continental scales.

In some situations, lack of specific climate data may be overcome by consulting available data in similar parts of the region, traditional knowledge and mapping, drawing from studies conducted under similar conditions, or by conducting new studies. Refer to Table 12 for information sources to support this task.

TABLE 12: ILLUSTRATIVE INFORMATION SOURCES

Type of Information	Source and Description
Development Frameworks	
USAID partner country priorities	• **USAID County Development Cooperative Strategies (CDCS)**
National development needs and investment areas	• **Poverty Reduction Strategy Papers (PRSPs);** Priority development goals, key limitations and challenges, policies and strategies, costs of achieving goals
National economic, political, social, and demographic data	• **Central Intelligence Agency (CIA) World Fact Book;** Recent data by country
National statistics on economy and climate stressors	• **Notre Dame Global Adaptation Index (ND-GAIN)**
Climate Change Strategies, Policies, and Plans	
Climate data and projections, assessments of vulnerability, and adaptation needs, priorities, and options by country	• **World Meteorological Organization (WMO):** A specialized agency of the United Nations for the provision of weather, climate and water cycle related information (https://www.wmo.int/pages/index_en.html) • **United Nations Environment Program (UNEP) Global Risk Data Platform:** Shares spatial data information on global risk from natural hazards (http://preview.grid.unep.ch/) • **UNEP Global Resource Information Database (GRID):** Provides information and publications to support decision making and policy setting (http://www.grid.unep.ch/index.php?lang=en) • **Intergovernmental Panel on Climate Change (IPCC):** Leading scientific body established by the United Nations to assess the risks from climate change. The IPCC summarizes the state of knowledge on climate change, examining published and peer-reviewed literature to develop three working group reports covering the Physical Science Basis of Climate Change; Impacts, Adaptation and Vulnerability; and Mitigation of Climate Change • **National Communications submitted to the United Nations Framework Convention on Climate Change (UNFCC):** Country context, broad priority development and climate goals, overviews of key sectors, historical climate conditions, projected climate changes and sectoral impacts, potential priority adaptation measures, and limitations, challenges, and needs • **National Adaptation Programmes of Action (NAPAs) submitted to the UNFCC:** Country context, key development and climate goals, historical climate conditions, projected climate changes and sectoral impacts, priority adaption needs and activities, and funding needs. May be out of date, and will be replaced by National Adaptation Plans in the future • **Famine Early Warning Systems Network (FEWS NET) Country Climate Trend Analysis Fact Sheets:** Summaries of historical climate trends over the past few decades, climate projections, and potential implications for food security in various countries
Existing and planned adaptation actions	• **Adaptation Partnership:** A review of existing and planned adaptations actions that includes a summary of regional needs and priorities and relevant policies and strategic documents
Adaption strategies, policies, and plans	• **Adaptation Learning Mechanism:** A knowledge-sharing platform that hosts a wide range of country-specific adaptation related information, including strategies, policies, and plans

*This table was adapted from Exhibit 3 on page 11 of USAID's Climate Resilient Development: A Framework for Understanding and Addressing Climate Change (2014).

CLIMATE DATA AND TRENDS

It is important to note in this chapter that there is a variety of sources from which data may be compiled. Scientific reporting is not a perfect substitute for local knowledge, nor is community input sufficient alone. When understanding climate change impacts on infrastructure activities two approaches should be considered:

- Looking at historical trends;
- Deriving local or regional projections from climate change models.

Both approaches have strengths and weaknesses. Elements of uncertainty and availability of resources will have to be addressed. Ideally, historical trends will be informed by input from stakeholders and reviewing local and regional weather data. When utilizing climate projections, it is important to consider the following:

- **Emissions scenarios** - Future climate projections should be based on high and moderate greenhouse gas emissions scenarios. Low emissions scenarios are very unlikely in the medium term, up to 50 years.
- **Time horizon** - The time horizon for the review is particularly important. For many assessments undertaken up to 2020, the generally recommended target points for evaluating climate risks are the years 2030, 2070, and 2100. However, if the required infrastructure is large-scale and requires significant investment with a design life of many years, it may be appropriate to design the asset for an end of century climate projections (e.g., bridges, hydro dams, tunnels). On the other hand, if the proposed infrastructure is predicted to have a shorter lifespan, then a 20-30 year climate change timeframe may be more appropriate. For more temporary developments, with a design life of only a few years, it is not necessary to design for future climate change. Rather, the design and planning efforts would consider current events, which may already include extreme weather events.

  Although there is a degree of uncertainty inherent with climate projections, as referenced above, prevailing general trends can often be established (e.g., hotter, wetter, windier). As data may not always be available for the interested time frame, other time horizons can be used to provide a baseline.
- **Data** - Variables such as air temperature, rainfall, and evaporation are highly interactive and a change in one variable will almost certainly result in a change in another variable. If different variables from different sources are mixed and combined in a single scenario, the resulting data may suggest implausible or impossible combinations or results (for example, combining the extreme wind output from one climate model with the extreme rainfall projection from another). A single, internally consistent future scenario should be used to assess potential climate change impacts, if possible. The preferred approach would be to create an ensemble of multiple climate model outputs, considering parameterization, and determine the range of possible wind and rain outcomes.

Table 13 is a regional climate projection example for a high greenhouse gas emissions scenario in 2020, 2030 and 2040 that includes precipitation and temperature climate changes. These climate projections were sourced specifically for the project and tailored to the scope of the risk assessment.

TABLE 13: EXAMPLE OF SUMMARIZED CLIMATE PROJECTIONS - HARYANA, INDIA

Season / Parameter	2020	2030	2040
Rainfall (%) Increase			
Annual	1.4% – 2.1%	2.1% – 2.9%	3.6% – 4.3%
Wet Season	0 – 0.7%	5.7% – 6.4%	8.6% – 9.3%
Dry Season	3.6% – 4.3%	0.7% – 1.4%	1.4% – 2.1%
Temperature (CC) Increase			
Annual	1ºC – 1.1ºC	1.5ºC – 1.6 ºC	2.2ºC – 2.3ºC
Wet Season	1ºC – 1.1ºC	1.5ºC – 1.6 ºC	2.3ºC – 2.4ºC
Dry Season	0.8 ºC – 0.9ºC	1.1ºC – 1.2 ºC	1.7 ºC – 1.8 ºC

SUMMARY CLIMATE CHANGE PROJECTION

The challenge of data collection is to gather available sources of information related to climate data in order to adequately address climate impacts on infrastructure assets. The preferred climate change projection approach would include a documented understanding of historical trends (includes local observation and the research of historical data, if possible) and projected changes. However, when gaps in data availability exist, it is necessary to acknowledge uncertainties in order to provide transparency to the assessment and a level of confidence.

CHECKLIST 1 - CONSIDERATIONS FOR ESTABLISHING THE CONTEXT

☐ **1. Identify project objectives in terms of:**
- Services to be delivered
- Physical asset attributes
- Per capita demand and total population to be served

☐ **2. Review future climate change impacts, including:**
- An appropriate time horizon (such as the middle or end of the century)
- All likely relevant stressors (e.g., temperature change, precipitation change, sea level rise, etc.)

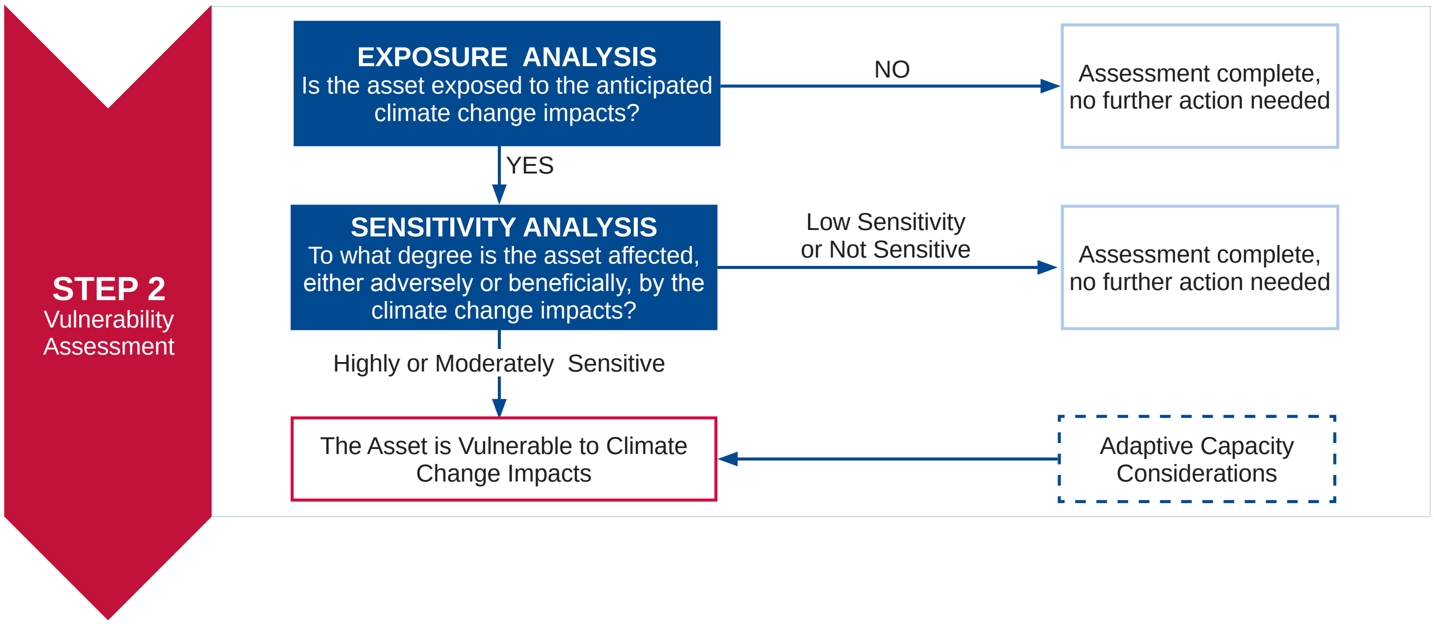
☐ **3. Review all external factors for relevance:**
- Cultural considerations
- Economic conditions
- Environmental and biophysical factors (not climate related)
- External institutional arrangements and stakeholders
- Legal and regulatory factors

☐ **4. Review internal factors for relevance:**
- USAID policies and requirements
- Governance arrangements and stakeholder participation in planning and implementation
- Funding and procurement conditions

CLIMATE MODELS

- Climate models are simulated representations of the earth's climate system based on its various components and interactions and feedback processes.
- The Intergovernmental Panel on Climate Change (IPCC) is the most credible source for the information that can be provided in global climate models (GCMs), however, information is not likely available at the local level.
- "Down-scaling" is a method developed to obtain local-scale weather and climate, particularly at the surface level resulting in a regional climate model.
- There are advantages and disadvantages for both. More information can be found on the IPCC website (http://www.ipcc.ch)

STEP 2: VULNERABILITY ASSESSMENT



CONDUCTING A VULNERABILITY ASSESSMENT

1. Analyze exposure of the asset to hazards using spatial information

2. Analyze sensitivity of the asset using a sensitivity matrix

3. Consider adaptive capacity

The second step in the overall approach considers the degree to which an infrastructure asset is susceptible when exposed to hazards identifying those that warrant more detailed investigation in Step 3. The vulnerability screening involves understanding an asset's vulnerability to specific climate change impacts over time. Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change (USAID, 2014) defines vulnerability as a function of an asset's exposure, sensitivity and adaptive capacity to a specific climate hazard.

DETERMINING ASSET EXPOSURE

Exposure is the nature and degree to which a structure or asset is subject to a climate impact. For example, a wastewater treatment plant likely to be impacted by tidal flooding as a result of sea level rise at mid-century would be exposed to this climate impact, whereas a plant that is not likely to be impacted by tidal flooding would be considered not exposed.

For each planned activity, determine whether or not it is likely to be exposed to the impacts identified in Step 1. Spatial information related to hazards will assist this process (e.g. flood hazard or other planning maps). Only those assets deemed to be exposed should progress to the assessment of sensitivity. If an asset or project site is not exposed to climate impacts then the assessment is complete at this point.

DETERMINING ASSET SENSITIVITY

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate stressors. For example, a substation at a wastewater treatment plant may be more sensitive to flooding than submersible mechanical equipment because substations are not designed to operate while inundated. In addition, water supply services are likely to be more sensitive to reductions in average precipitation than wastewater treatment services, because rainfall is not a key input into the wastewater treatment process, however, rainfall is a critical source of water for many regions. Table 14 outlines the levels of sensitivity ranging from Not Sensitive to High Sensitivity. Using this scale, project elements that are rated as having a Moderate or High Sensitivity would be deemed vulnerable to the climate impacts associated with the relevant climate hazard and be the focus of the risk assessment. To help inform sensitivity assessments, Table 15 provides a summary of the likely sensitivity of different types of infrastructure to different climate hazards.

TABLE 14: LEVELS OF SENSITIVITY TO CLIMATE CHANGE IMPACTS

Level of Sensitivity	Definition
NOT Sensitive	• No infrastructure service disruption or damage
LOW Sensitivity	• Localized infrastructure service disruption; no permanent damage • Some minor restoration work required
MODERATE Sensitivity	• Widespread infrastructure damage and service disruption requiring moderate repairs • Partial damage to local infrastructure
HIGH Sensitivity	• Permanent or extensive damage requiring extensive repair

Moderate or high sensitivity impacts are considered vulnerable and should be the focus of the risk assessment.

TABLE 15: LIKELY SENSITIVITY TO CLIMATE CHANGE

THEME	PROJECT	Extreme Heat	Drying Trend/ Dought	Extreme Precipi- tation/ Flooding	Storm Surge	Sea Level Rise	Damaging Storms (wind, lightning, snow/ice)	Wildfire
Energy	Power Distribution Facilities	MODERATE	LOW	LOW	HIGH	HIGH	HIGH	HIGH
	Oil Fueled Power Plants (non-renewable)	LOW	NOT	LOW	HIGH	HIGH	MODERATE	HIGH
	Small-Scale Hydro-Power Generation (renewable)	NOT	MODERATE	MODERATE	HIGH	HIGH	LOW	MODERATE
Environment	Flora and Fauna Protection	LOW	MODERATE	MODERATE	HIGH	HIGH	LOW	HIGH
	Rehabilitation	LOW	MODERATE	MODERATE	HIGH	HIGH	LOW	HIGH
	Land Management	LOW	MODERATE	MODERATE	HIGH	HIGH	LOW	HIGH
Flood Management	Embankments, Seawalls, Spurs, Floodgates	NOT	NOT	HIGH	HIGH	MODERATE	MODERATE	NOT
	Embankments, Levees, Dikes, Diversion Channels	NOT	NOT	HIGH	NOT	NOT	LOW	MODERATE
	Dams	NOT	NOT	HIGH	NOT	NOT	MODERATE	LOW
	Stormwater Networks	NOT	MODERATE	HIGH	MODERATE	MODERATE	MODERATE	LOW
Information and Communi- cations Technology	Fixed Line Systems	MODERATE	LOW	MODERATE	HIGH	HIGH	HIGH	HIGH
	Underground	NOT	MODERATE	MODERATE	HIGH	HIGH	NOT	LOW
	Transmission Facilities	MODERATE	LOW	MODERATE	HIGH	HIGH	HIGH	HIGH
Solid Waste	Processing Facilities	LOW	NOT	NOT	HIGH	HIGH	MODERATE	MODERATE
	Landfills and Disposal Facilities	LOW	NOT	MODERATE	HIGH	HIGH	MODERATE	HIGH
Transpor- tation	Roads	MODERATE	LOW	MODERATE	HIGH	HIGH	MODERATE	MODERATE
	Tunnels	NOT	LOW	MODERATE	HIGH	HIGH	LOW	LOW
	Bridges, Rail, Airports	MODERATE	NOT	MODERATE	HIGH	HIGH	MODERATE	HIGH
	Ports	MODERATE	NOT	LOW	HIGH	HIGH	HIGH	MODERATE

NOT Sensitive   LOW Sensitivity   MODERATE Sensitivity   HIGH Sensitivity

TABLE 15: LIKELY SENSITIVITY TO CLIMATE CHANGE (continued)

THEME	PROJECT	Extreme Heat	Drying Trend/ Dought	Extreme Precipi-tation/ Flooding	Storm Surge	Sea Level Rise	Damaging Storms (wind, lightning, snow/ice)	Wildfire
Vertical Structures	All Buildings (including schools, hospitals)	MODERATE	MODERATE	MODERATE	HIGH	HIGH	MODERATE	HIGH
	Structures of Cultural Heritage Value	MODERATE	MODERATE	MODERATE	HIGH	HIGH	MODERATE	HIGH
Wastewater and Sanitation	Latrines	LOW	LOW	MODERATE	HIGH	HIGH	MODERATE	MODERATE
	Septic, Leach Field Systems	NOT	LOW	LOW	HIGH	HIGH	NOT	LOW
	Sewerage Assets	NOT	MODERATE	MODERATE	HIGH	HIGH	NOT	LOW
	Wastewater Treatment	LOW	LOW	LOW	HIGH	HIGH	MODERATE	MODERATE
Water Supply	Surface Water Resources	LOW	HIGH	HIGH	MODERATE	HIGH	NOT	MODERATE
	Groundwater Resources	LOW	MODERATE	LOW	NOT	NOT	NOT	LOW
	Coastal / Island Freshwater Lenses	LOW	HIGH	MODERATE	HIGH	HIGH	NOT	NOT
	Alpine Water Resources (glaciers, snowpack)	HIGH	HIGH	MODERATE	NOT	NOT	NOT	MODERATE
	Water Quality	MODERATE	HIGH	HIGH	MODERATE	HIGH	LOW	HIGH
	Water Supply	LOW	MODERATE	HIGH	LOW	MODERATE	NOT	LOW
	Water Treatment	HIGH	MODERATE	HIGH	LOW	MODERATE	MODERATE	MODERATE
	Water Storage	LOW	MODERATE	HIGH	LOW	MODERATE	LOW	LOW
	Water Distribution	LOW	MODERATE	LOW	LOW	MODERATE	NOT	LOW

NOT Sensitive | LOW Sensitivity | MODERATE Sensitivity | HIGH Sensitivity

ASSESSING ADAPTIVE CAPACITY– OPTIONAL CONSIDERATIONS

Following the determination of an asset as vulnerable, practitioners may also consider the adaptive capacity of the infrastructure system. This step is not critical to the vulnerability screening process, however, it may provide useful information to inform the consequence discussion in Step 3.

Adaptive capacity is generally considered as a social component when working with soft infrastructure. When working with built or hard infrastructure, adaptive capacity refers to the ability to anticipate, prepare, and recover from climate impacts.

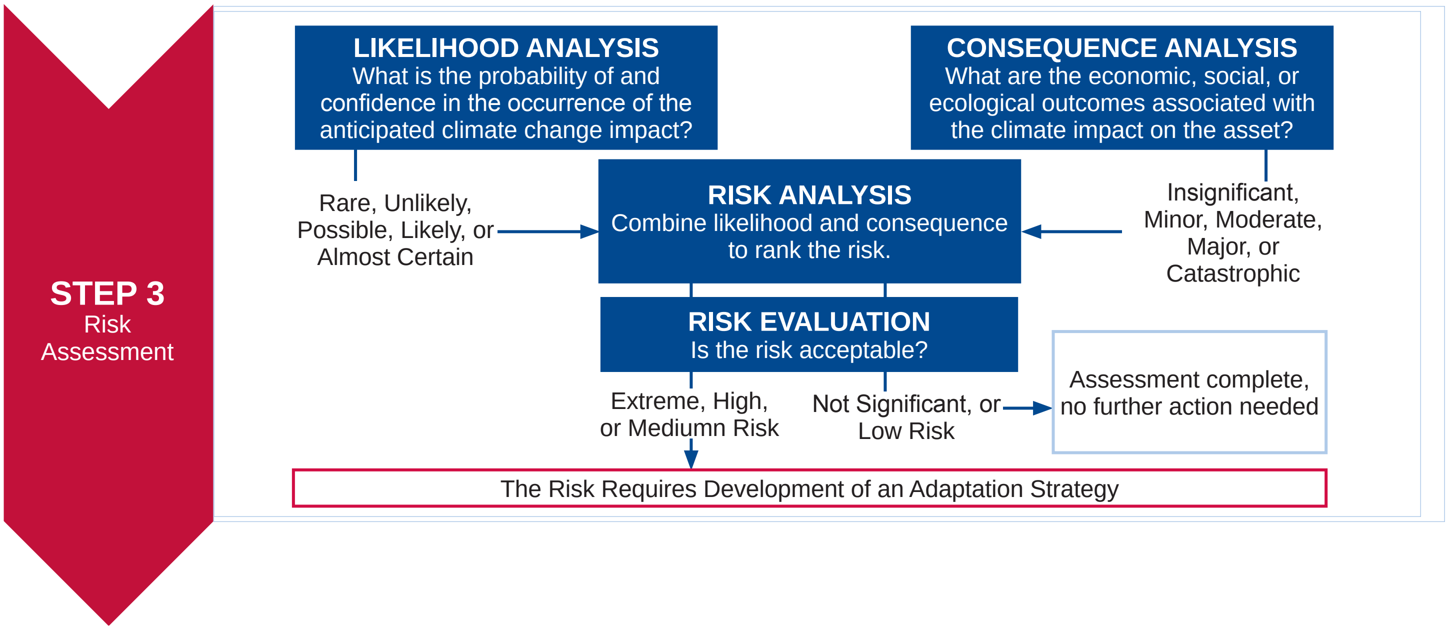
From a system perspective, this may be assessed by looking at core economic drivers in-country (or in similar contexts if not readily available), such as access to health services and education, resource strength in terms of wealth and human, strength of networks, institutions leadership, and disaster response mechanisms. Focusing on specific infrastructure, consideration may be given to the potential for supplementary capacity (e.g. redundancy), likely duration of a disruption to service or the duration of repairs to return an asset to operation.

CHECKLIST 2 - CONSIDERATIONS WHEN ASSESSING VULNERABILITY

- ☐ **1. To identify exposure and climate sensitivity, determine:**
  - Relevant climate effects, extremes, and other hazards
  - Relevant infrastructure assets and activities
- ☐ **2. Determine and document for each asset whether it has:**
  - 'High' sensitivity
  - 'Medium' sensitivity
  - 'Low' sensitivity
  - 'No or negligible' relationship or is not sensitive
- ☐ **3. Document those assets that are Vulnerable (e.g. those that are exposed and have Moderate or High sensitivity).**
- ☐ **4. Document adaptive capacity considerations (if assessed).**
- ☐ **5. Seek feedback from relevant (and local) stakeholders:**
  - Encourage engagement and endorsement by stakeholders in the vulnerability assessment process
  - Document material changes in ratings that result from stakeholder engagement.

Climate change is expected to increase the frequency and intensity of hurricanes and storms in many parts of the world, including Haiti. This section of Route Nationale 1, the major road connecting the northern part of Haiti with Port-Au-Prince and the southern part of the country, was washed away in a series of four hurricanes that devastated parts of Haiti in 2008.

STEP 3: RISK ASSESSMENT



CONDUCTING A RISK ASSESSMENT

1. Define the likelihood of climate impacts occurring
2. Understand the consequences of climate impacts
3. Conduct a risk analysis and develop a risk rating matrix
4. Accept the appropriate level of risk and adaptation needs

The third step of the approach enables practitioners to consider the risks to vulnerable assets. A risk assessment provides an analytical framework with qualitative descriptors for likelihood and consequences in a resulting risk matrix. Only those assets that have been identified as vulnerable in Step 2 need to be analyzed for risk.

Risks are often expressed as the combination of the consequences of an event and the associated likelihood that it will occur:

RISK = CONSEQUENCES x LIKELIHOOD

This approach is aligned with traditional risk management principles (e.g. ISO 31000:2009 *Risk management—Principles and guidelines*). Exposure and sensitivity data gathered in Step 2 can be used to inform the rating of likelihood and consequences.

UNDERSTANDING THE LIKELIHOOD OF CLIMATE IMPACTS

Table 16 provides examples of qualitative definitions that can be used to characterize the likelihood of a risk occurring. The probability of a risk occurring is often described in qualitative terms. Only when there is sufficient data and capability can a quantitative description of likelihood be made, where the time horizon is the life of the asset.

The level of certainty in determining the likelihood of a climate impact largely depends on the scale and certainty that the climate modeling exercise will yield (e.g., more frequent heat waves), changes in hydrological patterns (e.g., recurring floods), variations in coastal environments (e.g., sea level rise), and climate-driven gravitational hazards (e.g., higher frequency of rock falls, mudslides and avalanches). Regional models will likely yield more precise results with a smaller range of projections, providing greater certainty. Assumptions regarding uncertainties associated with the model, or a hypothesis when modeling is not possible, should be clearly articulated.

TABLE 16: EXAMPLE QUALITATIVE DEFINITIONS OF LIKELIHOOD

Level of Likelihood		Definition
5	Almost Certain	More likely than not, probability greater than 50%
4	Likely	As likely as not, 50 / 50 chance
3	Possible	Less likely than not but still appreciable, probability less than 50% but still quite high
2	Unlikely	Unlikely but not negligible, probability low but noticeably greater than zero
1	Rare	Negligible, probability very low, close to zero

UNDERSTANDING CONSEQUENCES OF CLIMATE IMPACTS

It is important to understand the consequences associated with an asset being impacted by a climate hazard. In some instances, the consequences can be very specific and defined for each sub-component of a large infrastructure system. For example, for a water supply system, different definitions of consequences may be applied for water treatment, water storage, and distribution assets. Defining consequences is ideally involves engaging key stakeholders to identify important criteria to be used to assess consequences. There may be one or several criteria used, depending on the project. Examples of consequence criteria which could be considered are listed below. Table 17 provides example definitions for rating each consequence criteria.

- **Asset Damage.** Damage requiring minor restoration or repair may be considered minor while permanent damage or complete loss of an asset would be considered to be a significantly higher consequence.
- **Financial Loss.** A high repair or capital replacement cost would be of major consequence compared to a cheaper repair or replacement cost.
- **Loss of Service.** As an example, a water system serving a large-scale industry with high water use requirements would be of major regional consequence compared to one serving a small-scale industry using less water. A bridge providing access to and from a port would be of major regional consequence compared to one serving a single farm.
- **Health and Safety.** A system serving a large number of people would be of major consequence compared to a system serving a smaller number. Casualties or other acute public health consequences would weigh more heavily.
- **Environmental Considerations.** Damage to a wastewater system adjacent to a local drinking water source, for example, would be of major polluting consequence compared to a system isolated from a local water source.
- **Reputation.** Loss of service, health or environmental impacts may affect the reputation of the responsible agency.

TABLE 17: EXAMPLE DESCRIPTOR FOR CONSEQUENCES		
Level of Likelihood		**Definition**
5	**Catastrophic**	• **Asset Damage:** Permanent damage and / or loss of infrastructure. • **Loss of Service:** Widespread and extended (several weeks) interruption of service of the agreed Level of Service; result in extreme contractual penalties or contract breach. • **Financial Loss:** Asset damage > annual maintenance budget or 75% of CAPEX value. • **Health / Safety:** Substantial changes to the health and safety profile; risk of multiple fatalities as a result of extreme events. • **Reputation:** Irreversible damages to reputation at the national and even international level / Public outrage.
4	**Major**	• **Asset Damage:** Extensive infrastructure damage requiring extensive repair / Permanent loss of local infrastructure services. • **Loss of Service:** Widespread and extended (several days) interruption of service for less than 50% of the agreed Level of Service; result in severe contractual penalties. • **Financial Loss:** Asset damage 50%+ of annual maintenance budget or 25% of CAPEX value. • **Health / Safety:** Marked changes in the health and safety profile, risk of severe injuries and even fatality as a result of extreme events. • **Reputation:** Damage to reputation at national level; adverse national media coverage; Government agency questions or enquiry; significant decrease in community support.
3	**Moderate**	• **Asset Damage:** Damage recoverable by maintenance and minor repair / Partial loss of local infrastructure. • **Loss of Service:** Widespread interruption of service for less than 20% of the agreed Level of Service; result in minor contractual penalties. • **Financial Loss:** Asset damage > 10% but < 25% of annual maintenance budget or 5% of CAPEX value. • **Health / Safety:** Noticeable changes to the health and safety profile, risk of severe injuries as a result of extreme events. • **Reputation:** Adverse news in media / Significant community reaction.
2	**Minor**	• **Asset Damage:** No permanent damage / Some minor restoration work required. • **Loss of Service:** Localized interruption of service for less than 10% of the agreed Level of Service. • **Financial Loss:** Asset damage > 5% but < 10% of annual maintenance budget or 1% of CAPEX value. • **Health / Safety:** Slight changes to the health and safety profile; risk of minor injuries as a result of extreme events. • **Reputation:** Some adverse news in the local media / Some adverse reactions in the community.
1	**Insignificant**	• **Asset Damage:** No infrastructure damage. • **Loss of Service:** Localized interruption of service for less than 1% of the agreed Level of Service (LoS). • **Financial Loss:** Asset damage < 5% of annual maintenance budget or negligible CAPEX value. • **Health / Safety:** Negligible or no changes to the health and safety profile or fatalities as a result of extreme events. • **Reputation:** Some public awareness.

CONDUCTING A RISK ANALYSIS

Once the likelihood and consequence are defined, the risk level is determined by multiplying the likelihood value by the consequences value to result in a score from 1 (Low) to 25 (Extreme). Generally, the resulting score will be assigned one of five levels of risk: Not Significant, Low, Medium, High, or Extreme (Table 18).

TABLE 18: RISK RATING MATRIX

Level of Risk		Consequence Level				
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Likelihood Level	Almost Certain (5)	Medium (5)	Medium (10)	High (15)	Extreme (20)	Extreme (25)
	Likely (4)	Low (4)	Medium (8)	High (12)	High (16)	Extreme (20)
	Possible (3)	Low (3)	Medium (6)	Medium (9)	High (12)	High (15)
	Unlikely (2)	Low (2)	Low (4)	Medium (6)	Medium (8)	Medium (10)
	Rare (1)	Not Significant (1)	Low (2)	Low (3)	Low (4)	Medium (5)

TABLE 19: EXAMPLE RESPONSES AND ACCEPT ABILITY FOR DIFFERENT LEVELS OF RISK

Level of Risk	Definition
EXTREME ≥ 20	• Extreme risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations • These risks are not acceptable without treatment
HIGH 12-16	• High risks are the most severe that can be accepted as a part of routine operations without executive sanction, but they are the responsibility of the most senior operational management and reported upon at the executive level • These risks are not acceptable without treatment
MEDIUM 5-10	• Medium risks can be expected to form part of routine operations, but they will be explicitly assigned to relevant managers for action, maintained under review and reported upon at the senior management level • These risks are possibly acceptable without treatment
LOW ≤ 4	• Low risks will be maintained under review, but it is expected that existing controls will be sufficient and no further action will be required to treat them unless they become more severe • These risks can be acceptable without treatment

DETERMINING RISK ACCEPTABILITY AND THE NEED FOR ADAPTATION

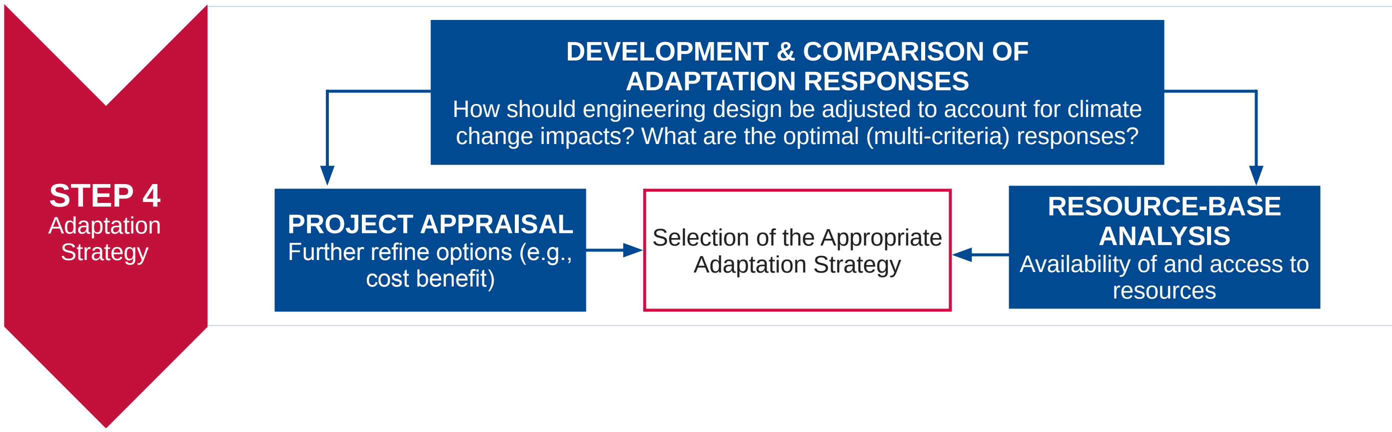
Based on the outcomes of the risk analysis, it is necessary to determine and prioritize those risks requiring treatment with appropriate adaptation measures. Risk acceptability criteria need to be defined (refer to Table 19) to guide the determination of which risks are determined to be acceptable and the most significant risks requiring treatment (i.e. adaptation planning).

Often the risk evaluation is led by a project funder or leader, rather than the technical staff who lead the risk analysis. Decisions on risk treatment should take into account the acceptability of external stakeholders that are likely to be affected.

CHECKLIST 3 - CONSIDERATIONS FOR ASSESSING RISK

- ☐ **1. Establish risk rating criteria including definitions for likelihood, consequences and a risk rating matrix.**
- ☐ **2. Identify the anticipated climate change impact, associated risks and relevant infrastructure.**
- ☐ **3. Consider the use of hazard modeling that factors in regional climate projections to inform the risk rating.**
- ☐ **4. Rate likelihoods and consequences of risks.**
- ☐ **5. Document the most significant risks requiring adaptation.**

STEP 4: DEVELOPING AN ADAPTATION STRATEGY



DEVELOPING AND SELECTING AN ADAPTION RESPONSE

1. Identify potential adaptation solutions
2. Conduct project appraisal (e.g., CBA) to further refine and generate a shortlist of adaptation options
3. Consider the availability and access to resources, human and material
4. Develop the adaptation strategy with the identified adaptation solutions

Once the degree of vulnerability has been established and the most critical risks have been identified, a decision can been made regarding how to address the risks. A range of adaptation strategies are available when preparing for and adapting to climate change impacts. Selection of a strategy is dependent on a number of factors, including location, temporal scale, and the specific impacts faced.

Understanding the available resource base to implement the infrastructure activity will also be important. While some adaptation options may require little resources (e.g., training or monitoring) others may prove more cost-intensive.

Four generally accepted types of adaptation responses that can be implemented include 1) accommodate and maintain; 2) harden and protect; 3) relocate; and 4) accept or abandon. Table 20 provides an overview of each approach for new and existing infrastructure which help to prompt thinking and idea generation for the development of adaptation options. Chapter 4 provides additional detail on each approach and includes examples of adaptation options for multiple infrastructure types.

TABLE 20: APPROACH TO ADAPTATION STRATEGIES

Strategic Approach		Adaptation Strategy	
		Existing Structure	New Structure
1	Accommodate and Maintain	• Extend, strengthen, repair or rehabilitate over time • Adjust operation and maintenance	• Design and build to allow for future upgrades, extensions or regular repairs
2	Harden and Protect	• Rehabilitate and reinforce • Add supportive or protective features • Incorporate redundancy	• Use more resilient materials, construction methods, or design standards • Design for greater capacity or service
3	Relocate	• Relocate sensitive facilities or resources from direct risk	• Site in area with no, or lower, risk from climate change
4	Accept or Abandon	• Keep as is, accepting diminished level of service or performance	• Construct based on current climate, accepting possibly diminished level of service or performance

Once a range of possible adaptation options has been identified, they should be prioritized to create a shortlist of the most appropriate options for implementation. A number of approaches are available, including decisions strictly based on best judgment and not including detailed analysis and justification. Common approaches to shortlist options include the use of a Multi-Criteria Analysis (MCA) and applying an economic analysis, such as Cost-Benefit Analysis (CBA), to further refine and prepare for implementation.

Once the adaptation strategies have been chosen, an adaptation strategy can be prepared. The aim of the adaptation plan is to support the implementation of the selected measures. It would typically include:

1. Technical requirements refer to the core technical aspects required to implement the measures. They should consider whether these are readily available in the area and how mature is the proposed technology.

2. Funding requirements. Any measure would require some degree of funding whether in terms of capital or maintenance costs. The total funding requirements and possible funding sources and contribution by partners and other stakeholders (including in kind contributions from communities) should be documented.

3. A budget breakdown for delivery is complementary to the funding requirement but gives specific details on how the budget will be used to deliver the measure. It can include a breakdown between materials, labor and additional activities such as monitoring and communication. The timeframe or schedule for expenditure is also important.

4. Roles and responsibilities outline the requirements of the different stakeholders involved in implementing the measures.

5. An exit plan would identify how the measure and its associated benefits can be maintained once USAID support is no longer available. It can include additional donor funding, local contributions and other actions to support the long term viability of the measure.

6. A detailed program provides a time schedule of the different activities required and their sequencing as relevant.

7. Capacity building activities (if required). The local capacity might not be sufficient to maintain and operate the infrastructure and capacity building might be required to enable the effective implementation and maintenance of risk treatment measures.

Sector specific primers have been developed to provide detail on different potential adaptation strategies addressing many of the points listed above.

SHORT-LISTING OF ADAPTATION SOLUTIONS

MULTI-CRITERIA ANALYSIS

MCA is a comparative assessment of options, taking account of several criteria simultaneously. It is mainly used to assess aspects that either cannot be readily quantified in monetary terms or at stages in options development where detailed cost implications have not yet been developed. MCA should also be used to identify flaws and identify options that will not be considered for further analysis.

The advantage of MCA is that it can account for environmental and social impacts that are not easily assigned monetary values since measurement of indicators does not have to be undertaken in monetary terms. The disadvantage of MCA is that it is subjective.

In the context of refining a long list of potential options under consideration, MCA can be used to rank or short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities. The objective is to determine the performance of a number of options in regard to a set of relevant criteria.

A selection of the following criteria may be used to determine the most acceptable adaptation option to address identified risks:

1. Community and stakeholder acceptability. Not all options will have the same degree of acceptance by local stakeholders and the community because of cultural, economic or environmental side effects, as well as behavior change requirements.

2. Functional effectiveness. Each option will have a different potential level of effectiveness to respond to the potential impacts of climate change; this can include realization of benefits, increased resilience, or reduction in exposure of hazards.

3. Technical feasibility. Some options based on complex technology can be at varying degrees of maturity and application; the local conditions can also limit the technical feasibility of a particular type of option.

4. Ease of implementation and construction. This refers to the barriers and opportunities to implement options and construct

assets; this can include human capital, availability of materials and existing technical skills.

5. Durability / maintenance requirements. What is the robustness of the proposed option? What is its likely effective period and maintenance requirements?

6. Timeframe for implementation of the option.

7. Lead-time until effectiveness. Some options can be implemented rapidly but the full benefits will not be realized immediately, such as revegetation or infrastructure rehabilitation.

8. Adequacy with current climate and flexibility in the face of climate change. Are the proposed options compatible with existing climate conditions?

9. Indicative costing. This includes a broadly defined cost estimate of the options to be implemented.

10. Anticipated number and type beneficiaries. How widely will the benefits from the option be realized?

The weight given to these different criteria will vary between applications, as decided by the user. Determining the relative weighting can be undertaken through a paired comparison, where a user ranks each individual criteria against every other criteria to determine a ranking of priority criteria. Alternatively, users can identify specific fundamental criteria, such that failure to meet the criteria may eliminate the option altogether.

Once the criteria and weighting have been determined, the options can be assessed. This assessment should ideally be developed using a participatory approach with key stakeholders. The final score can be reached either through consensus among the workshop participants or by averaging the individual scores given by participants (either approach is effective and may be selected depending on the number of participants in the MCA and the format of the engagement).

The MCA will generate a short-list from the original long-list of potential options. At this point, a more detailed analysis may be required to select adaptation options based on economic analysis of their merits and value-for-money.

Table 21 provides an example of the outputs of an MCA exercise. In this example a number of options were analyzed in terms of: 1) improving the resilience of potable water assets; 2) better managing demand; and 3) limiting degradation of the resources.

TABLE 21: EXAMPLE OF A COMPLETED MULTI-CRITERIA ANALYSIS

Criteria	Effectiveness	Expected Beneficiaries	Cost	Speed	Technical Feasibility	Acceptability	**Total**
Weighting Factor	0.2	0.3	0.23	0	0.2	0.07	**1**
Supply Assets Move Raw Water Intake Facilities	5	5	2	2	3	4	**3.8**
Supply Assets Anti-Corrosion Program	4	4	4	4	5	5	**4.3**
Demand Increasing Community Awareness	3	3	5	5	4	5	**3.8**
Demand Encourage Water Savings Through Water Tariffing	5	5	5	5	5	3	**4.9**
Resources Build Raw Water Storage Upstream	5	4	2	2	4	2	**3.6**
Resources Construct Dykes To Prevent Salinity Intrusion	4	5	1	1	5	1	**3.6**

NOTE: A score on a scale of 1 (poor) to 5 (excellent) is allocated to each criteria.

ECONOMIC ANALYSIS OF SHORTLISTED OPTIONS

Economic analysis and in particular cost-benefit analysis (CBA) is the most commonly accepted approach to compare and further refine adaptation or risk treatment options.

The benefit of each adaptation option is measured by the reduction in the climate change induced cost of damages between now and a time in the future (discounted to current dollars) to provide an estimate of the present value of benefits from implementing options.

The implementation and operating costs of each adaptation option is estimated and combined with any residual cost of climate impacts. A cost benefit analysis is then used to appraise and compare different adaptation option or groups of options.

Key considerations that should be included as part of the CBA process include:

1. The discount rate.
2. Sensitivity analysis of inputs to influence the results of the CBA.
3. Explanation and documentation of assumptions and uncertainties.
4. The boundary of the analysis (e.g. how widely are the benefits received and who pays).

CHECKLIST 4 - CONSIDERATIONS FOR DETERMINING ADAPTATION STRATEGY

☐ **1. Identify Adaptation Solutions.**

☐ **2. Determine Approach to shortlist possible adaptation solutions:**
- Multi-criteria Analysis
- Economic analysis (e.g. CBA)

☐ **3. Implement Prioritization.**

☐ **3a. For MCA, agree on the relevant criteria for the MCA:**
- Community and stakeholder acceptability
- Functional and lead time until effectiveness
- Technical feasibility
- Ease of implementation in construction and management
- Durability and maintenance requirements
- Time frame
- Adequacy with current climate patterns
- Indicative costs

☐ **3b. Determine scoring weight for each criteria and perform comparison analysis.**

☐ **3c. Consider use of cost-benefit tool to further scale-down short-listed options and determine feasibility.**

DISCOUNT RATES

The selection of an appropriate social discount rate for projects that involve long evaluation periods and benefits that accrue long into the future is a matter of considerable debate in academic, governmental, and professional circles.

It is an important consideration as climate change adaptation projects tend to have early costs with benefits accruing later, resulting in more favorable CBA results if low discount rates are employed.

STEP 5: IMPLEMENTATION

IMPLEMENTING THE ACTIVITY

1. Provide on-going monitoring and evaluation to consider change in risk status

2. Identify and develop best practice examples to integrate into future design processes

3. Conduct consultation and transparent communication with all stakeholders involved to promote buy-in and better understanding of local context

Implementation of climate change adaptation programs may be defined solely as an engineering program, but will likely be part of a larger program that includes planning and zoning, government and stakeholder buy-in, and many other complex factors.

MONITORING AND EVALUATION

Most projects and programs include monitoring and evaluation activities that can be adjusted to cover climate change risks. If feasible, embedding climate change risks in an existing monitoring and evaluation framework is the preferred approach, rather than developing a stand-alone climate change risk monitoring and evaluation framework.

Ongoing monitoring and evaluation activities can help consistently adjust the risk assessment and management approach and support development of risk treatments that are effective, contribute to improvements in risk understanding, detect changes in external and internal conditions, and identify emerging risks.

Monitoring and evaluation should be based on robust, and simple to measure, quantitative and qualitative indicators. Careful consideration should be given to the cost efficiency and ease of measurement for the proposed measures. Information can be collected and analyzed through both participatory and external evaluation. Local communities can take a very active role in monitoring tasks.

IMPLEMENTING BEST PRACTICES

Monitoring and evaluation provides organizations with an opportunity to identify assets susceptible to climate change impacts and better inform future asset planning. For example, asset condition deterioration profiles may change where assets are exposed to more extreme conditions.

Climate change adaptation is an emerging field, so implementation is also experimentation in some cases. Both successes and failures should be reported and documented to build a community of practice so that climate change adaptation strategies improve over time and practitioners become more conversant in implementing such strategies.

COMMUNICATION AND CONSULTATION

Climate change risk communication activities should ideally form part of the overarching outreach and communications plan for each infrastructure asset.

Communication and consultation should ideally take place during all risk management activities. A robust and consistent communications plan including consideration of potential climate change risks and selected adaptation options should be developed in close collaboration with implementing partners and stakeholders. A communication plan should outline how the findings of the analysis will be made accessible to support decision making and general awareness raising for both technical and non-technical audiences.

Different target groups (e.g., government agencies, businesses, communities, and women and children) and different communication vehicles (e.g., workshops, reports, animations, summary sheets, and fact sheets) should be considered. Ongoing communication and consultation activities can support the development of appropriate objectives and understanding of the local context, help ensure that climate risks are correctly identified, and help build consensus among stakeholders on the findings of the risk assessment and the risk treatment selected for implementation.

CHECKLIST 5 - CONSIDERATIONS FOR IMPLEMENTING INFRASTRUCTURE ACTIVITIES

- ☐ **1. Consider and integrate monitoring and evaluation at all stages of the activity cycle.**
- ☐ **2. Identify best practices and integrate into future design.**
- ☐ **3. Consider and consult key stakeholder where possible and appropriate, to promote good communication practices:**
    - Local experts
    - International experts

GETTY

CHAPTER 4

ADAPTATION STRATEGIES

ADAPTATION STRATEGIES TO ENABLE CLIMATE RESILIENT INFRASTRUCTURE

Adaptation encompasses all the actions in response to actual or projected climate change impacts to reduce risks, vulnerability, and related future costs. There are many adaptation strategies that can improve resiliency to the climate change impacts described in Chapter 2 (Climate Change Impacts and Risks). These strategies can be categorized under four main approaches: accommodate and maintain, harden and protect, relocate and accept or abandon. Each of the approaches have unique advantages and disadvantages as summarized in Table 22.

In some cases, it might be adequate to alter operation and maintenance regimes to allow assets to perform to design specifications (accommodate and maintain). Adaptation strategies to harden and protect involve specific engineering measures that can be incorporated into the design of a infrastructure system to make it more resilient to climate change – such as incorporation of redundancy, use of more resilient materials, building to a more robust standard, or the construction of flood or sea level rise protection barriers. Adapting to climate change may require shifting the location of assets to avoid hazards, for example, or in extreme cases accepting the climate hazard and abandoning an asset. Table 23 illustrates an array of the different

CHOOSING THE RIGHT APPROACH

The diverse array of adaptation strategies and responses for more climate resilient infrastructure design can be categorized under four main approaches:

1. Accommodate and maintain
2. Harden and protect
3. Relocate
4. Accept or abandon

TABLE 22: ADVANTAGES AND DISADVANTAGES OF ADAPTATION APPROACHES

Strategic Approach		Advantages	Disadvantages
1	Accommodate and Maintain	• Less costly • More pragmatic and flexible, allows adjustment over time as more climate change data becomes available	• Requires monitoring, possibly frequent repairs, adjustments, or more rigorous operations • Necessitates design for more flexible or upgradeable structure
2	Harden and Protect	• Proactive • Straightforward to implement and justify	• Increased costs • Assumes reasonably accurate climate forecasts
3	Relocate	• Proactive	• Increased costs • Sub-optimal location may decrease period of performance or service
4	Accept or Abandon	• No extra up-front cost	• Proper communications needed to inform decision-makers and beneficiaries to expect lower performance or service

types of strategies that may be implemented for different types of assets in response to different climate variables and their impacts.

While anticipating the need for adaptation measures is most cost effective during the engineering design phase of the infrastructure project cycle introduced in Section 1, it may be necessary to make reactive adjustments to project designs to reduce the vulnerability to climate change impacts. In cases where infrastructure projects were conceived without consideration of climate change impacts, it may also be necessary to retrofit existing assets or redesign programs. Once a list of potential adaptation strategies has been identified, multi criteria analysis (MCA) or cost-benefit analysis (CBA) as described in Step 4 (Developing an Adaptation Strategy) can be used to shortlist or refine strategies.

At the end of this section, example adaptation strategies are provided for multiple climate drivers. The sector specific primers should be referenced for more detail on each of the adaptation strategies appropriate for that specific sector.

TABLE 23: ILLUSTRATIVE ADAPTATION STRATEGIES

Climate Drivers	Affected Asset and Risk	Engineering Design Adaptation Strategies
Extreme Heat/ Heatwaves	• Health facility • Loss of power and air conditioning to manage excessive heat increases health risk to patients	• **Harden:** Enhance design to enable additional cooling and ventilation capacity • **Accommodate:** Install emergency back-up generators
Drying Trend/ Drought	• Trunk sewer system • Reduced flow in pipelines causes increased blockages, and potential for environmental pollution	• **Harden:** Redesign sewer for low flow conditions (e.g., install smaller pipes) • **Accommodate:** Facilitate and increase maintenance
Extreme Precipitation/ Flooding	• River embankment • More frequent submersion, lesser level of protection, and possible breach / failure of embankment	• **Harden:** Heighten or buttress embankment based on long-term projected floods • **Accommodate:** Slightly heighten embankment • **Relocate:** Build behind a new embankment (maybe only to protect sensitive or urban areas) • **Accept:** Inform residents and farmers to expect lesser protection and increased flooding (possibly dismantle embankment to avoid disastrous failure)
Storm Surge	• Seawall • Structural damage and submersion leading to property or asset damage and potential loss of life	• **Harden:** Heighten and reinforce seawall, or build offshore breakwaters • **Accommodate:** Monitor and repair as needed • **Relocate:** Build new seawall further away from the coast • **Abandon:** Relocate properties and condemn area for future development (possibly dismantle seawall to avoid disastrous failure)
Sea Level Rise	• Coastal road • Often submerged at high tide, preventing traffic and distribution of goods	• **Relocate:** Move road inland • **Harden:** Elevate road or build sea wall • **Accommodate:** Monitor and close road at high tide • **Abandon:** Close road and redirect traffic permanently to more inland routes
Damaging Storms (wind, lightning)	• Coastal wind turbines • Damage from windblown debris	• **Harden:** Enhance wind resistance design • **Accommodate:** Stop operation during storms • **Abandon:** Dismantle and build other energy production system (e.g., solar) as a substitute
Wildfire	• Potable water supply • Burned catchment causes ash and sediments to impact water quality of water sources	• **Harden:** Install additional filtration • **Accommodate:** Reforest, stabilize slopes, build sedimentation traps • **Relocate:** Build raw water intake and conveyance from other nearby catchment

STRATEGIES TO ACCOMMODATE AND MAINTAIN

As regional climate changes over the life of the asset, the functioning performance of asset may be inhibited and its design life expectancy shortened. Therefore the incorporation of climate adaptation into the asset management process is vital to ensure desired value and performance can still be achieved. This includes updating management policies, regulations, and maintenance and operations activities. It may also include reassessing the availability of natural resources utilized by the asset (such as water) or re-evaluating the demand for services provided by the infrastructure asset, and adjusting service expectations and operational cycles accordingly. An important part of these strategies may also include updating emergency and disaster management plans.

DEFINING LEVEL OF SERVICE TO BE PROVIDED

Asset management is driven by level of service targets, regulatory and legislative requirements, and strategic and management objectives. It is therefore necessary for asset managers to understand whether climate change impacts may affect the ability of their organization to meet existing level of service targets or regulatory and legislative requirements. It is also necessary to understand whether these requirements might change as a direct result of climate change. For example, more frequent and extended periods of drought may require the need to impose water restrictions more regularly, which would affect service delivery. In such circumstances, an organization would be faced with the decision of whether to maintain existing serve delivery and asset performance, requiring an increase in expenditure on assets and operations, or whether to accept the changes in asset performance in order to minimize expenditures associated with adaptation.

OPERATIONS AND MAINTENANCE

Operations and maintenance practices may need to be modified in an attempt to reduce the possible impacts of climate change. This might include adjustments to the frequency of maintenance activities, or to the mix of reactive and preventative maintenance. In addition, the choice of materials and adopted maintenance standards may require modification (see Table 23). Examples include increased salinity in coastal areas resulting in increased corrosion for water treatment assets or increased ground movement (as a result of extended and increased periods of dry or wet and cold or hot cycles) which is very likely to result in increased operation and maintenance costs for buried assets and foundations of existing assets.

CHANGES IN DEMAND FOR SERVICES

Climate change may result in a change to the demand profile. For example, the service requirements of water dependent industries from some areas might result in reductions in peak demand, thereby increasing system redundancy. An organization will therefore be required to assess whether to continue to maintain or dispose of excess redundancy in the asset base. Reductions in demand for water will also reduce wastewater volumes, in turn reducing the volume of treated effluent available for reuse. Alternatively, increases in demand may lead to network constraints, requiring the creation of new assets. Changes in the demand profile may also consist of a combination of the above impacts over different time periods, for example, during heat waves, on a seasonal basis, or multi-annually (extended drought).

CHANGES IN RESOURCES

Furthermore, potential impacts of climate change could also affect the reliability of resources. For example, sustained reductions in the yield of bore fields (consequences of reduced mean rainfall and aquifer recharge) may influence the security of water supply and an organization’s ability to guarantee service levels unless another source is identified and secured.

STRATEGIES TO HARDEN AND PROTECT

Options under this approach involve structural changes to how an infrastructure system is designed, built, renovated or protected. Protect and harden strategies include actions such as upgrading design standards to use stronger building materials and reinforcing or fortifying planned or existing structures. While often more resource-intensive in terms of the financing, technical, and organizational capacity required, these actions can be most cost-effective in the long term.

RETROFITTING AND REHABILITATION

Asset managers must periodically assess whether it is necessary to renew or rehabilitate assets in order to maintain their condition and performance. These decisions should be made in light of asset lifecycle costs.

It is important to consider whether climate change will have an impact on the life expectancy of existing assets. For example, shrinking and swelling of clay soils might compromise the structural integrity of underground assets, reducing their effective life. While it may have been cost effective to rehabilitate certain assets in the past, increases in maintenance and rehabilitation costs may mean that it is more cost effective to replace or renew the asset.

MATERIALS SELECTION

A number of the strategies listed in the tables above identify selection of appropriate or more resilient materials as one adaptation option. Table 24 summarizes the sensitivity of different materials to the various climate variables in temperate climates only to help give an indication of the materials to specify to give a higher range of resilience to changing climate conditions.

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TABLE 24: DIFFERENTIAL IMPACT OF CLIMATE EFFECTS ON MATERIALS

Material	Carbon Dioxide	Cyclones & Storms	Sea Level Rise	Extreme Rainfall & Floods	Annual & Max Temp	Ultraviolet Radiation	Wildfire	Drought
Concrete	M	H	H	M	M	L	M	L-M
Metals	L	H	H	M	M	L	H	L
Mortar	L	M	M	M	L	L	M	H
Timber	L	M	M	M-H	M	L	E	L-M
Coatings	L	M	L	M	M	H	E	L
Polymers	L	M	L	L	M	H	E	L

*Tested on commonly used materials in engineering designs for temperate climates only (©AECOM – Climate sensitivity of materials research, S.E. Australia Region 2007)

L Low M Moderate H High H Extreme

STRATEGIES FOR RELOCATION

Relocation strategies seek to reduce the degree of exposure to climate variables and the risks they impose on infrastructure assets. Once a shortlist of adaptation options has been identified, managers select a course of action. The course of action may be to relocate an asset to an area less exposed to the identified climate variables of impact, such as moving a coastal water treatment plant further inland.

STRATEGIES FOR ACCEPT OR ABANDON

Accept or abandon is the most passive approach, as it is basically a do-nothing strategy. The future, decreased service, performance or lifespan of the asset is accepted due to lack of funding, resources or willingness to do better (possibly also due to greater priorities elsewhere). It is important the practitioners make sure that both the decision-makers and beneficiaries understand the implications of this approach.

MONITORING AND EVALUATION OF ADAPTATION STRATEGY EFFECTIVENESS

Asset monitoring throughout the life of assets is required to keep track of their performance and to identify under-performing assets. Where assets are identified as being sensitive to climate change, and measures to mitigate the impacts of climate change have been identified (as described above), the effectiveness of these measures should be monitored throughout the life of the asset.

Measuring the performance and condition of assets will also assist the relevant organization in identifying assets susceptible to climate change impacts, and better inform future asset planning. For example, asset condition deterioration profiles may change where assets are exposed to more extreme conditions.

EXAMPLES OF ADAPTATION STRATEGIES

Many adaptation measures are not exclusive to a specific type of infrastructure and can be considered for any infrastructure activity. Some examples where these adaptation measures are considered across infrastructure types for a particular climate change impact are provided in Table 25 below. Table 26 to Table 34 provide additional sector specific adaptation strategies. Most of these examples include engineering design measures to harden and protect, as these are the main focus of this document.

TABLE 25: CROSS SECTORAL INFRASTRUCTURE
Adaptation Strategies for Climate Resilient Design

Climate Drivers	Adaptation Measures
Extreme Precipitation Events, Flooding	• Undertake a detailed flood modeling analysis and relocate asset to an area of lower risk • Increase carrying capacity of stormwater drainage system and retention basins • Stabilize slide-prone area, slopes, embankments • Use water proof or corrosion resistant matrials • Build to a more robust standard for long life and critical facilities in vulnerable locations
Sea Level Rise and Storm Surge	• Relocate asset to an area of lower risk • Create a barrier to protect against future sea level rise (e.g. build or raise levee, floodwall, revetment, bulkhead, riprap, create or enhance wetlands, undertake beach nourishment) • Construct offshore breakwaters • Install storm surge barriers • Use green engineering measures such as mangrove and reef rehabilitation to increase shoreline protection and storm surge buffers
Wildfires	• Relocate asset to an area of lower risk, • Use heat resistant construction materials or coatings • Maintain and implement vegetation management practices that aim to minimize fire risk

TABLE 26: ENERGY INFRASTRUCTURE — NON-RENEWABLES, RENEWABLES AND DISTRIBUTION SYSTEMS

Adaptation Strategies for Climate Resilient Design

Climate Change Effect	Adaptation Measures
Extreme Precipitation Events, Flooding	• Allocate sufficient budget for repair and recovery after extreme events (often more cost effective than relocation, especially for large facilities) • Cyclone proof wind turbine in cyclone prone areas (existing system where the turbine can be easily removed from the axis and secured to the ground) • Reinforce overhead transmission lines and apply hydrophobic coating or install lines and equipment underground • Relocate or protect energy substations
Drought; Reduced Average Precipitation	• Assess the proportion of water flows that is dependent on glacier or snow fed rivers and integrate this component in the design and exploitation of the facility (hydro) • Manage water in an integrated framework to avoid use conflict (hydro) • Give priority to drought resistant species where possible (biofuels)
Extreme Heat	• Improve energy efficiency and reduce the demand on the network • Increase peak generation capacity (e.g. gas peaking plant or hydro reserve) • Diversify fuel sources
Sea Level Rise and Storm Surge	• Consider multiple combinations of waves' direction and height in the design to maximize the potential for energy generation

TABLE 27: ENVIRONMENTAL ASSETS

Adaptation Strategies for Climate Resilient Design

Climate Change Effect	Adaptation Measures
Extreme Heat, Wildfires	• Use planning controls to restrict development and provide reserves for biodiversity corridors • Select species that are suited to likely future climate conditions • Undertake vegetation management practices that minimize fire risk
Sea Level Rise and Storm Surge	• Use planning controls to restrict development and provide reserves for biodiversity corridors to support retreat of vegetation • Select species that are suited to likely future climate conditions

TABLE 28: FLOOD MANAGEMENT INFRASTRUCTURE
Adaptation Strategies for Climate Resilient Design

Climate Drivers	Adaptation Measures
Sea Level Rise and Storm Surge	• Consider future climate in design of coastal protection assets • Beach nourishment and dune construction • Revegetation of coastal areas • Storm surge barriers, barrier islands, and tide gates
Extreme Precipitation Events, Flooding	• Consider future climate in design of asset to manage larger peak water flows • Combine open space and stormwater storage to manage peak flows • Provide, maintain and provide training on the use of temporary flood barriers to protect critical infrastructure • Flood education, awareness and emergency management training for at risk communities • Revegetation of catchments

TABLE 29: INFORMATION AND COMMUNCATION TECHNOLOGY INFRASTRUCTURE
Adaptation Strategies for Climate Resilient Design

Climate Drivers	Adaptation Measures
Damaging Storms	• Maintain vegetation management practices that minimize the chance of contact being made that may damage infrastructure • Allocate sufficient budget for repair and recovery after extreme events (often more cost effective than relocation, especially for large facilities) • Install communication lines underground • Consider future climate in design of asset to manage increased risk of flooding and storm damage
Extreme Precipitation Events, Flooding	• Install temporary, or permanent flood barriers to key facilities • Consider future climate in design of asset to manage increased risk of flooding

TABLE 30: SOLID WASTE INFRASTRUCTURE
Adaptation Strategies for Climate Resilient Design

Climate Drivers	Adaptation Measures
Extreme Precipitation Events, Flooding	• Relocate landfills or construct levee or other protective barrier
Extreme Heat	• Reassess management and covering of landfill to control decomposition and potential odors • Reassess management of dry matter in landfill to protect against fire

TABLE 31: TRANSPORTATION INFRASTRUCTURE
Adaptation Strategies for Climate Resilient Design

Climate Drivers	Adaptation Measures
Extreme Precipitation Events, Flooding	• Alter maintenance regimes to target vulnerable sections of transport systems • Size drain and stormwater systems with a consideration of climate change projections. If no projections are available, include a precautionary overestimation in the design to provide a safety buffer • Harden or stabilize slopes subject to increased run off from extreme weather events • Seal ventilation grates of below ground facilities • Elevate mechanical and electrical equipment in operations or maintenance facilities • Use waterproof materials • Review capacity of pump equipment
Sea Level Rise and Storm Surge	• Raise elevation of track, roadway, or bridge touchdown, on embankments or levees • Construct causeway • Elevate mechanical and electrical equipment in operations or maintenance facilities • Increase capacity of stormwater drainage system and increase drainage maintenance at flooding hotspots • Use corrosion-resistant or waterproof materials • Construct low-water crossings
Extreme Heat	• Confirm capability of current heat-resistant road and track materials and if necessary use more heat tolerant binders and materials

TABLE 32: VERTICAL STRUCTURES
Adaptation Strategies for Climate Resilient Design

Climate Drivers	Adaptation Measures
Increase in Annual Average Temperature	• Design buildings to reduce solar gain and to take advantage of local natural breezes for ventilation to decrease need for cooling and to make building more habitable
Extreme Precipitation Events, Flooding	• Diversify energy supplies, including local solar generation in case of grid outage • Improve local stormwater drainage against to buildings; minimize hard standing • Install increased capacity stormwater management systems • Install green roofs to slow run off • Raise grade of building • Have no habitable rooms on the ground floor elevation
Greater Variability in Wet / Dry Spells	• Design building foundations that will be resistant to swelling and shrinking soils through flexible joints etc.

TABLE 33: WASTEWATER AND SANITATION INFRASTRUCTURE
Adaptation Strategies for Climate Resilient Design

Climate Drivers	Adaptation Measures
Extreme Precipitation Events, Flooding	• Design sewage system with inclusion of changing precipitation projections • Size drain and stormwater systems with a consideration of climate change projections. If no projections are available, include a precautionary overestimation in the design to provide a safety buffer • Planning of retention and safety basins to avoid overflow to the drainage network and pollution spills downstream • Integrate flood management procedures (forecasting and early warning systems) in sewer and landfill operational planning • Elevate mechanical and electrical equipment in operations or maintenance facilities • Use waterproof materials • Review capacity of pump equipment
Sea Level Rise and Storm Surge	• Review location of outfall pipes (in relation to potential backflow)
Extreme Heat	• Equip the sewage system with independent power generation backup to ensure pump power supply during electricity blackout

TABLE 34: WATER SUPPLY INFRASTRUCTURE
Adaptation Strategies for Climate Resilient Design

Climate Drivers	Adaptation Measures
Extreme Precipitation Events, Flooding	• Use mesh and specific filters to minimize the potential of stationary water becoming a breeding area for mosquitoes • Design efficient irrigation systems with inclusion of precipitation projections • Size drain and stormwater systems with a consideration of climate change projections • Increase water efficiency by using drip feed systems • Relocation of raw water intake
Sea Level Rise and Storm Surge	• Raise elevation of storage infrastructure to protect from saltwater intrusion • Elevate mechanical and electrical equipment in operations or maintenance facilities • Increase capacity of stormwater drainage system and increase drainage maintenance • Use corrosion-resistant or waterproof materials • Reduce pumping from freshwater lenses to inhibit saline intrusion
Drought, Reduced Average Precipitation	• Consider alternative water supply options (e.g. recycled water systems) and conservation measures (e.g. restrictions on water use) • Increase the individual capacity and the number of rainwater tanks • Relocation of raw water intake • Diversify water sources such as new water storages or expanding their existing capacity, tapping deeper groundwater aquifers, inter-basin water transfer, capturing unharnessed resources such as rainwater harvesting, desalination, or employing water reuse technologies • Increase reservoir capacity • On-site recycling of used water or decentralized treatment (industrial reuse and small local use)

GETTY

RISK ASSESSMENT AND CLIMATE CHANGE ADAPTATION FOR A LAKE BASIN IN CHINA

CASE STUDY

This case study demonstrates the methodology presented in this guide. It is focused on a large freshwater lake basin in mainland Asia. The basin's water resources are threatened by projected increases in average annual temperature, changes in precipitation patterns, and drought. The risk management approach stakeholders used to transition a qualitative discussion into a semi-quantitative assessment of climate risks and appropriate adaptation measures is strongly aligned with the "ISO 31 000 Risk Management – Principles and Guidelines."

STEP 1: ESTABLISHING THE CONTEXT

To establish the context, available local historical data (Figure 4) was used to determine the current climate for the basin. Analysis of historic climate trends was based on fifty years of daily observation records from 79 weather stations in the lake's region. Climate modeling was undertaken for the 2010-2050 time horizon using a set of 17 different models and a high greenhouse gas emissions scenario. Data revealed that the basin area is characterized by a marked dry season. A summary of current versus future climate conditions is provided in Table 31 with the confidence in the trends and projections provided for the important climate effects.

STEP 2: VULNERABILITY ASSESSMENT

Risk screening was undertaken by preparing a risk screening matrix, which was based on the identified key climate trends with risk assessment aspects considered. The risk screening matrix in Figure 5 illustrates a number of relationships. On the far left side, the matrix shows the relationships between core elements (e.g., agriculture) and sub-elements (e.g., rice production). Notice that sub-elements may be linked to more than one core element. These sub-elements form a matrix with climate effects, which illustrate if there is a relationship between a particular climate variable (e.g., extreme rainfall) and the sub-element.

Relationships are identified as being strong, minor, uncertain, distant, or non-existent. Where strong or minor relationships are identified between the sub-elements and climate variables, these are transformed into risk scenarios and become part of the detailed risk assessment. The summary of the vulnerability assessment is provided Figure 5, which highlights relationship of core elements and sub-elements to key climate effects. This prioritizes focus for the risk assessment and the climate related information that needs to be collected. It was not possible to get extreme wind data for this location for past or future climate conditions.

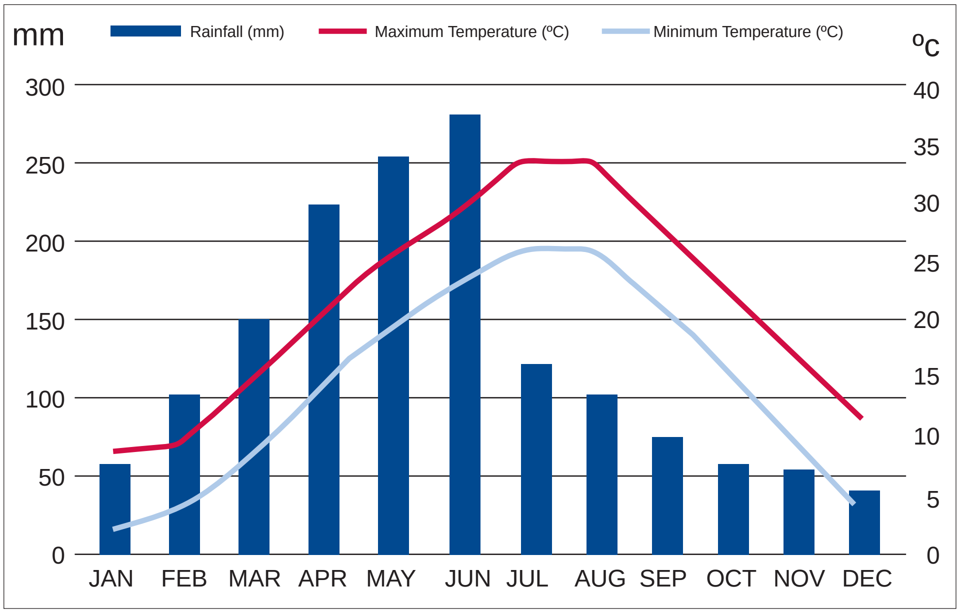

FIGURE 4: CLIMATE PROFILE FOR THE CASE STUDY BASIN

TABLE 31: CLIMATE MODELING REVEAL PROJECTED CLIMATE TRENDS

Climate Driver	Current (Confidence)	Future (Confidence)
Mean Temperature	Increase (High)	Increase (Medium / High)
Extreme Heat	Increase (High)	Increase (Medium / High)
Extreme Cold	Decrease (High)	Decrease (Medium / High)
Mean Rainfall	Minimal change (Medium / High)	Minimal change (Low / Medium)
Extreme Rainfall	Decrease (Low)	Decrease (Low)

INCREASE DECREASE = MINIMAL CHANGE

FIGURE 5: VULNERABILITY SCREENING MATRIX

Key Climate Driver

Core Element - Sub-Element(s)
AGRICULTURE - 1,2,3,4,5,6
INDUSTRY - 6,7
PUBLIC HEALTH - 8,9,10
LIVELIHOODS - 6,11,12,13
BIODIVERSITY - 6,14
TOURISM - 14

	Sub-Element	Extreme Heat	Mean	Extreme Cold	Drought	Mean Rainfall	Extreme Rainfall	Floods
1	Pests / Vermin	Uncertain	Uncertain	Uncertain	Uncertain			
2	Rice Production	Strong	Strong	Strong	Strong	Minor		Minor
3	Citrus Production	Minor	Strong	Strong	Minor			Minor
4	Forestry	Minor	Minor	Minor		Minor	Minor	
5	Fisheries and Aquaculture				Strong			
6	Water Resources	Minor	Minor		Strong	Strong	Minor	Minor
7	Lake Water Level	Minor	Minor		Strong	Minor		
8	Schistosomiasis		Strong				Strong	Strong
9	Cold Spell Related Facilities			Strong				Strong
10	Heatwave Related Facilities	Strong						
11	Water Quality for Human Consumption							
12	Subsistence Fishing				Strong			
13	Subsistence Agriculture	Strong	Minor	Strong	Strong	Minor	Strong	Minor
14	Wetland Ecosystems (inc. migratory birds)				Strong	Minor	Minor	Minor

STRONG RELATIONSHIP MINOR RELATIONSHIP UNCERTAIN RELATIONSHIP DISTANT OR NO RELATIONSHIP

STEP 3: RISK ASSESSMENT

Based on the vulnerability screening steps presented above almost 30 risks were identified and analyzed; most of the risks are likely to result in negative impacts while a few might present positive impacts (opportunity). For the purpose of this project risk has been assessed as a function of the likelihood of the risk occurring and its resulting consequences. The climate change risks are assigned of likelihood level and consequence level ranging from 1 to 5, creating a combined risk rating on a scale of up to 25 (Table 32).

A rated risk example is provided below demonstrating how reasoning behind the rating is detailed in Figure 6 for clarity of assessment conclusions and assumptions.

TABLE 32: RISK RATING SCALE USED TO EVALUATE RISK

		CONSEQUENCES				
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
LIKELIHOOD	Almost Certain (5)	MEDIUM (5)	MEDIUM (10)	HIGH (15)	EXTREME (20)	EXTREME (25)
	Likely (4)	LOW (4)	MEDIUM (8)	HIGH (12)	HIGH (16)	EXTREME (20)
	Possible (3)	LOW (3)	MEDIUM (6)	MEDIUM (9)	HIGH (12)	HIGH (15)
	Unlikely (2)	LOW (2)	LOW (4)	MEDIUM (6)	MEDIUM (8)	MEDIUM (10)
	Rare (1)	NOT	LOW (2)	LOW (3)	LOW (4)	MEDIUM (5)

FIGURE 6: RATED RISK EVALUATION

Risk	Likelihood	Consequence	Risk 2050
Reduced surface water resources as a result of increased frequency and intensity of drought events and increases in mean temperature and extreme heat events. Surface water resources account for 96% of total water supply in Jiangxi Province (see Figure 41). Increases in the frequency and intensity of drought events, mean temperature and extreme heat all contribute to a decrease in surface water resources. Rising mean temperature and increases in the frequency and intensity of extreme heat events increase evaporation rates of surface water, the watershed and water reservoirs.	**4 - LIKELY** Mean temperature is likely to increase by 2050, along with the frequency and intensity of extreme heat events, resulting in reduced surface water recharge rates by 2050, particularly during droughts. The trend of droughts out to 2050 is uncertain for the Poyang Lake Basin; however, the potential for increases in frequency and intensity of droughts should be considered.	**4 - MAJOR** With surface water resources accounting for 96% of total provincial water supply, a reduction in this resource would have a significant impact causing widespread disruption to water supply in the Province.	**16 - HIGH**

STEP 4: DEVELOPMENT OF AN ADAPTATION STRATEGY

Key climate change risks considered in the adaptation strategy included:

- Reduction in surface water resources;
- Decline in agricultural yields (including fisheries and forestry);
- Decrease in water availability for key industries;
- Public health impacts in particular increased transmission and diffusion of Schistosomiasis (a vector borne disease influenced by temperature and flood patterns) and extreme heat;
- Potential degradation of key natural resources (water and subsistence farming) for local livelihood systems; and
- Potential decline in biodiversity values (migratory birds and wetlands).

A list of 12 possible adaptation measures was identified to address some of the most threatening risks. Most of these measures focus on a specific sector, and two of them were general measures. Table 33 below presents these possible measures.

STEP 5: IMPLEMENTATION

Using a Multi-Criteria Analysis, the possible adaptation measures were shortlisted for implementation. Some measures were integrated in a broader management approach (integrated lake management) while others have been selected for further analysis and possible implementation including a drought management plan (including temporary water restrictions), a heat wave management plan, the Schisiostomasis management plan and early warning system.

TABLE 33: SHORTLIST OF ADAPTATION STRATEGIES GENERATED FROM MCA

Sector or Priority	Strategy
Water	• Drought management plans • Permanent (seasonal) water restrictions
Lake Level	• Improve management of the lake water level
Agriculture	• Improve crop variety, Optimize agricultural layout and adjust cropping system • Economic diversification strategy for the agricultural sector
Industry	• Water audits for water intensive industries • Water management plans for water intensive industries
Public Health	• Schisiostomasis management plan for the Jiangxi Province • Schisiostomasis early warning system • Heat wave management plans
General	• Climate change awareness program for communities, government, and businesses • Climate change monitoring and open data access


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SUGGESTED RESOURCES

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