A GUIDE FOR USAID PROJECT MANAGERS

# POTABLE WATER

INCORPORATING CLIMATE CHANGE ADAPTATION IN INFRASTRUCTURE PLANNING AND DESIGN

NOVEMBER 2015

ACKNOWLEDGMENTS

This guide was developed for the United States Agency for International Development (USAID) by AECOM as part of a series of sector specific climate change adaptation manuals prepared for the USAID-funded Global Climate Change, Adaptation, and Infrastructure Issues Knowledge Management Support Project.

COVER PHOTOS

The cover photo shows that water infrastructure projects link previously under-served communities to reliable water and sanitation services (credit: USAID Environmental Cooperative - Asia). The second image shows Northwestern Rural Development Project Cambodia (credit: AECOM).

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

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AECOM

A METHODOLOGY FOR INCORPORATING CLIMATE CHANGE ADAPTATION IN INFRASTRUCTURE PLANNING AND DESIGN

# POTABLE WATER


DeNatale, AECOM

# CONTENTS

# ACRONYMS

| | |
|---|---|
| CAPEX | Capital Expenditure |
| CBA | Cost-Benefit Analysis |
| GHG | Greenhouse Gas |
| MCA | Multi-Criteria Analysis |
| MDG | Millennium Development Goal |
| OPEX | Operational Expenditure |
| UNDP | United Nations Development Programme |
| USAID | United States Agency for International Development |
| WSUD | Water Sensitive Urban Design |

# 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 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.

**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** service smaller populations, ranging from villages to clusters or communities of households, and are often more relevant to 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.


Mozambique

# 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 has been created, led by the *Overarching Guide: A Methodology for Incorporating Climate Change Adaptation in Infrastructure Planning and Design*. The overall objective of the Overarching 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 2014 USAID publication, *Climate Resilient Development: A Framework for Understanding and Addressing Climate Change*, the Overarching Guide provides engineering and non-engineering development professionals with a methodology to evaluate infrastructure vulnerability and select appropriate engineering design options to build resilience.

As a part of the suite of tools for incorporating climate resiliency into engineering design, this particular guide concentrates on potable water infrastructure, with the overall objective of supporting the consideration of climate change risks and adaptation in USAID potable water infrastructure development activities. This guide will be useful for those considering specific engineering design options to make potable water infrastructure more resilient in a climate altered future. It provides engineering and non-engineering development professionals with an overview of potential impacts on potable water activities and adaptation options, and guidance for utilizing a risk assessment methodology to determine appropriate design measures.

While the focus of this guide is on engineering design; broader elements such as service delivery and management of supply and demand are also proposed as they are closely associated with the optimum performance of potable water infrastructure. The focus of this document is not on mitigation of greenhouse gas emissions related to potable water infrastructure construction or operation.

### A SUITE OF TOOLS

Accompanying this potable water guide are additional primers that focus on flood management, roadways, bridges, sanitation, and irrigation, that provide more detail on climate change impacts and appropriate adaptation responses and strategies for these other important infrastructure sectors.

## THE IMPORTANCE OF CONSIDERING CLIMATE CHANGE IMPACTS IN POTABLE WATER INFRASTRUCTURE

Climate change is likely to exacerbate issues and constraints concerning water resources and infrastructure. The risks associated with climate change are broad and diverse. They may include, for example, reduced availability of rainwater, surface water and groundwater resources, or physical damage to potable water storage, treatment and distribution systems from flooding. Changes in climate patterns and natural hazards are likely to affect the operational profiles of existing infrastructure and bring additional challenges to the development, construction, and operation of new infrastructure. It is important for practitioners and stakeholders to consider the nature and extent of climate change impacts on investments and activities related to both new and existing infrastructure.

When considering the impact of climate change on potable water infrastructure, it is important to understand the relevance and cost-effectiveness of climate change adaptation activities. If the infrastructure asset is a short-term or temporary solution, or if the project is small, it may not be necessary to fully assess longer term climate change risks to the investment. If the asset is large or expected to last more than three decades, climate change risks should be considered. For example, the design and construction of a reservoir with a design life of 100 years or more should consider climate change impacts. On the other hand, a small-scale pipeline that can be repaired cost effectively following an extreme climate event may not need to be fully climate resilient.

Climate stressors will also impact, and involve consequent risks to, major types of both large and small scale potable water infrastructure. These risks to assets include physical damage, inefficient design of new assets, degradation of water quality, and higher operating costs.

## A STEPWISE APPROACH TO CLIMATE RESILIENT DESIGN

Following a climate resilience framework when developing and evaluating potable water infrastructure design will help practitioners improve the effectiveness of these investments. USAID's *Climate Resilient Development Framework*[1] 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).

This framework should be used by practitioners to establish what climate change impacts existing or future infrastructure assets might be facing (e.g., sea level rise ,flooding, drought, and increase in number of extreme heat days); whether or not the asset might be sensitive to those changes; and how such sensitivities impact the asset. The subsequent risk assessment will help identify those assets whose failure would have significant or severe impacts on buildings, economic activities, and/or public health. Adaptation strategies should then be defined and implemented.

## ADAPTATION STRATEGIES AND RESPONSES

Responding to climate change impacts will require the selection of appropriate adaptation strategies. These strategies should be selected based upon the previous assessments conducted under the Climate Resilient Design Methodology (see Chapter 3) and take into consideration a country's priorities, availability of resources, and temporal-scale of the activities.

The diverse array of adaptation strategies and responses for enabling more climate resilient infrastructure design can be categorized under four types of strategic approaches: 1) accommodate and maintain; 2) harden and protect; 3) relocate; and 4) accept or abandon. Each approach has advantages and disadvantages that are expanded upon in Chapter 3. Examples of climate impacts and risks, and adaptation measures relevant to potable water infrastructure are provided in Table 1. A compendium illustrating adaptation strategies available to practitioners to address potential climate change- related risks to potable water infrastructure is also provided in the Annex.

[1] USAID. 2014. Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change. Washington, D.C., available at http://www.usaid.gov/climate/climate-resilient-development-framework

### TABLE 1: EXAMPLES OF POTABLE WATER INFRASTRUCTURE RISKS AND ADAPTATION MEASURES

| Climate Drivers | Climate Impacts and Risks | Adaptation Measures |
|---|---|---|
| Drought, Reduced Average Precipitation, Increased Surface Water Temperature, Wildfires | • Decreased availability of surface water resources, increased need for additional groundwater sources (or deeper wells and increased pumping costs to reach deeper groundwater tables)<br>• Seasonal water shortages<br>• Decline in raw water quality of surface water due to algal blooms and increased treatment requirements<br>• Decreased supply and thus intermittent or low pressure delivery, with increased risk of contamination from wastewater intrusion<br>• Increased demand for urban and industrial water supplies may result in reduced availability of water for irrigation<br>• Decreased water quality from particulates caused by loss of vegetation due to wildfire | • Increase the individual capacity and the number of rainwater tanks<br>• Relocation of raw water intake<br>• 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<br>• Asses the utility's flexibility to switch between different water sources<br>• Consider alternative water supply options (e.g. recycled water systems) and conservation measures (e.g. restrictions on water use)<br>• Implement water metering and tariff management to reduce water consumption<br>• On-site recycling of used water or decentralized treatment and non-potable reuse<br>• Maintain and implement vegetation management practices that aim to minimize fire risk |
| Extreme Precipitation Events, Less frequent but higher intensity storms, Flooding | • Flooding and stormwater infrastructure damage<br>• Physical damage to structures,<br>• Lower treatment effectiveness, or increase treatment cost, due to turbidity | • Increase carrying capacity of stormwater drainage system and retention basins<br>• Stabilize slide-prone area, slopes, and embankments<br>• Implement Water Sensitive Urban Design strategies for stormwater management and replenishment of groundwater resources<br>• Elevate mechanical and electrical equipment in operations or maintenance facilities |
| Sea Level Rise and Storm Surge | • Saline intrusion into freshwater supplies<br>• Corrosion of intake or conveyance structures<br>• Flooding and infrastructure damage | • Undertake a detailed flood modeling analysis and relocate asset to an area of lower risk<br>• Raise elevation of storage infrastructure to protect from saltwater intrusion<br>• Elevate mechanical and electrical equipment in operations or maintenance facilities<br>• Increase capacity of stormwater drainage system and increase drainage maintenance<br>• Use corrosion-resistant or waterproof materials<br>• Reduce pumping from freshwater lenses to inhibit saline intrusion |

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**Washing in River Hatit**

CHAPTER 1

# INTRODUCTION

## POTABLE WATER INFRASTRUCTURE

In 2010, the global Millennium Development Goal (MDG) of halving the percentage of the world's population without sustainable access to safe drinking water was met. The number of people using improved water sources reached 6.1 billion, an increase of over 2 billion people since 1990. However, the United Nations' 2012 *The Millennium Development Goals Report* acknowledges that although the global target has been met, a number of challenges remain. Of the currently estimated 783 million people lacking access to safe drinking water worldwide, 99 percent (773 million) are in developing countries. It is also important to note that the MDG drinking water target is not yet able to account for water quality in terms of safety, reliability, and sustainability of water resources.

There continues to be great need for development organizations, national governments, and the private sector to continue to work together to provide investments and direct technical assistance to increase access to potable water in developing countries. Decision-making on appropriate planning and implementation approaches for a diverse range of solutions are dependent on the local context, such as water source availability, reliability, quality, water demand, and socioeconomic profile.

## CLIMATE CHANGE IMPACTS ON POTABLE WATER INFRASTRUCTURE

Climate change is likely to exacerbate existing issues and constraints concerning water resources and infrastructure. The risks associated with climate change are broad; they include direct reduction in available rainwater, surface water and groundwater resources, decline in the quality of surface water and groundwater resources, physical damage to potable water storage, treatment, and distribution systems from extreme events. If these risks are not carefully considered in new potable water activities, they could prevent emerging countries from meeting their MDGs or cause the reversal of recent development gains.

Practitioners and aid recipients need to be aware of the nature and extent of climate change impacts and future climate variability on investments and activities; this could include activities related to both new and existing infrastructure. Future climate conditions must be considered when planning and managing most aspects of infrastructure activities, including the justification for project activities, definition of the level of services, location, design, operation, maintenance, renewal, and refurbishment.

Climate change is a significant threat to poverty reduction activities and could jeopardize decades of development efforts. From the very beginning, investment plans and the design process, development of new infrastructure and rehabilitation of existing infrastructure should be designed to be resilient to climate risks.

## HOW TO USE THIS GUIDE

The overall objective of this guide is to support the consideration of climate change risks and adaptation in USAID potable water infrastructure development activities. It provides engineering and non-engineering development professionals with a guidance document demonstrating a step-by-step method for assessments and supporting technical information, including an overview of potential impacts on potable water activities, adaptation options, case studies and resources. This guide will be useful for those considering how climate change may require specific infrastructure projects (e.g., a design for a specific water treatment plant) to be altered to enhance resilience. This guide will also be useful to those considering how to meet service goals in a climate altered future.

This potable water guide accompanies an Overarching Guide that covers integration of climate change adaptation considerations into a broad range of USAID infrastructure activities. The overarching methodology offers a step-wise process for implementing a risk assessment framework. This guide is specific to potable water infrastructure.. Note that some content is repeated in both guides to maintain readability of each document.

This guide addresses climate change adaptation rather than mitigation of greenhouse gas emissions. The focus of this guide is on engineering activities; however, broader elements such as service delivery, demand and supply management are also included for consideration, because they are closely associated with the optimum performance of potable water infrastructure.

**Reservoir sediment accumulation depends on the sediment sources from the upland areas and flows that may erode and transport them. Climate change is expected to alter future sediment loads affecting maintenance requirements and ultimately the functional life of a reservoir.**

GETTY


DeNatale, AECOM

**Haiti**

CHAPTER 2

# CLIMATE IMPACTS AND RISKS

## CLIMATE IMPACTS AND RISKS TO POTABLE WATER INFRASTRUCTURE DESIGN

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. The following sections provide an overview of the risks that climate change may pose to water supply systems, and how to manage or minimize these risks in the development or rehabilitation of potable water assets. The range of risks discussed is not exhaustive; practitioners should conduct a detailed assessment at the project or program level to identify all relevant risks.

## KEY CONSIDERATIONS IN IDENTIFYING IMPACTS TO POTABLE WATER INFRASTRUCTURE

Climate change is likely to impact potable water infrastructure assets through modification in the pattern of extreme climatic events, which includes storms and storm surge, 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 risk to potable water 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 when designing or rehabilitating infrastructure, 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.

## 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.

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.

## 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 comprehensive assessment.

***Climate change can cause direct physical impacts 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 on might be impacted, thereby rendering associated infrastructure redundant or over-designed. For example, water distribution systems might be physically unaffected by a drought, but if water resources are diminishing, 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 asset life spans 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 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.*** For example, warmer temperatures and more frequent heat waves can lead to increased demand for water. Demographic expansion or contraction, 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.*** For example, inadequate power distribution services during an extreme climate event can impact or exacerbate access to potable water in systems using pumps, access which may already be strained during a drought.

## POTENTIAL IMPACTS ON WATER SUPPLY INFRASTRUCTURE

The map on the following page illustrates the potential climate impacts on potable water infrastructure and systems. Potential climate impacts on water supply infrastructure associated with extraction, treatment, storage, and distribution structures (treatment facilities, reservoirs, and networks) include:

***Reduced precipitation.*** Direct changes in precipitation patterns and indirect changes in land use within the catchment can negatively impact surface water and groundwater availability.

***Changes in the seasonality of precipitation patterns.*** This may affect the reliable yields from surface water reservoirs.

***Change in snow, glacial and rain cycles.*** Rising temperatures and changes in precipitation can significantly alter the hydrology pattern in mountainous areas as the thawing period lengthens and the snow line retreats to higher elevations. Short-term impacts due to snow melt could be beneficial as water resource availability temporarily increases, but long-term negative impacts can be more significant once existing ice reserves and snow pack have disappeared.

***Increased intensity of storms and extreme precipitation.*** Beyond the physical damage to structures, and the potential for flooding, the potential occurrence of such events requires the increased attention as to the siting and sizing of structures, notably spillways for reservoirs and overflows for extraction and conveyance structures.

***Droughts.*** Prolonged drought can cause groundwater levels to drop significantly, either temporarily or permanently, thereby affecting the capability of water extraction measures designed to withdraw groundwater at specific depths.

***Sea level rise.*** This will directly threaten flood coastal structures such as desalination plants, while the water extraction area may also be impacted by increased salinity. Small volcanic or coral quays often have a lens of freshwater floating on a transition zone of brackish water that lies on top of saltwater. Expected climate change impacts such as sea level rise and changes in tropical cyclone patterns may exacerbate the risks to freshwater lenses due to salinization.

***Decrease in water quality.*** Multiple climate-influenced factors can negatively impact water quality in a variety of ways, including increased siltation, algal blooms, and decreased capacity for dilution of water contaminants. This can be particularly important when selecting sites for water extraction. Changes in water quality can also hinder treatment processes and require more rigorous (expensive) measures. Increased salinity and reduced precipitation may impact shallow aquifers or reduce surface water dilution of salinity, impacting potable water supplies, irrigation water, or infrastructure longevity (e.g., building foundations). Increased saline intrusion is also associated with climate change, especially in coastal areas affected by sea level rise.

***Increased mean temperature.*** Evaporation losses from surface water reservoirs may be expected to increase as temperatures increase, thereby reducing yields and increasing storage losses.

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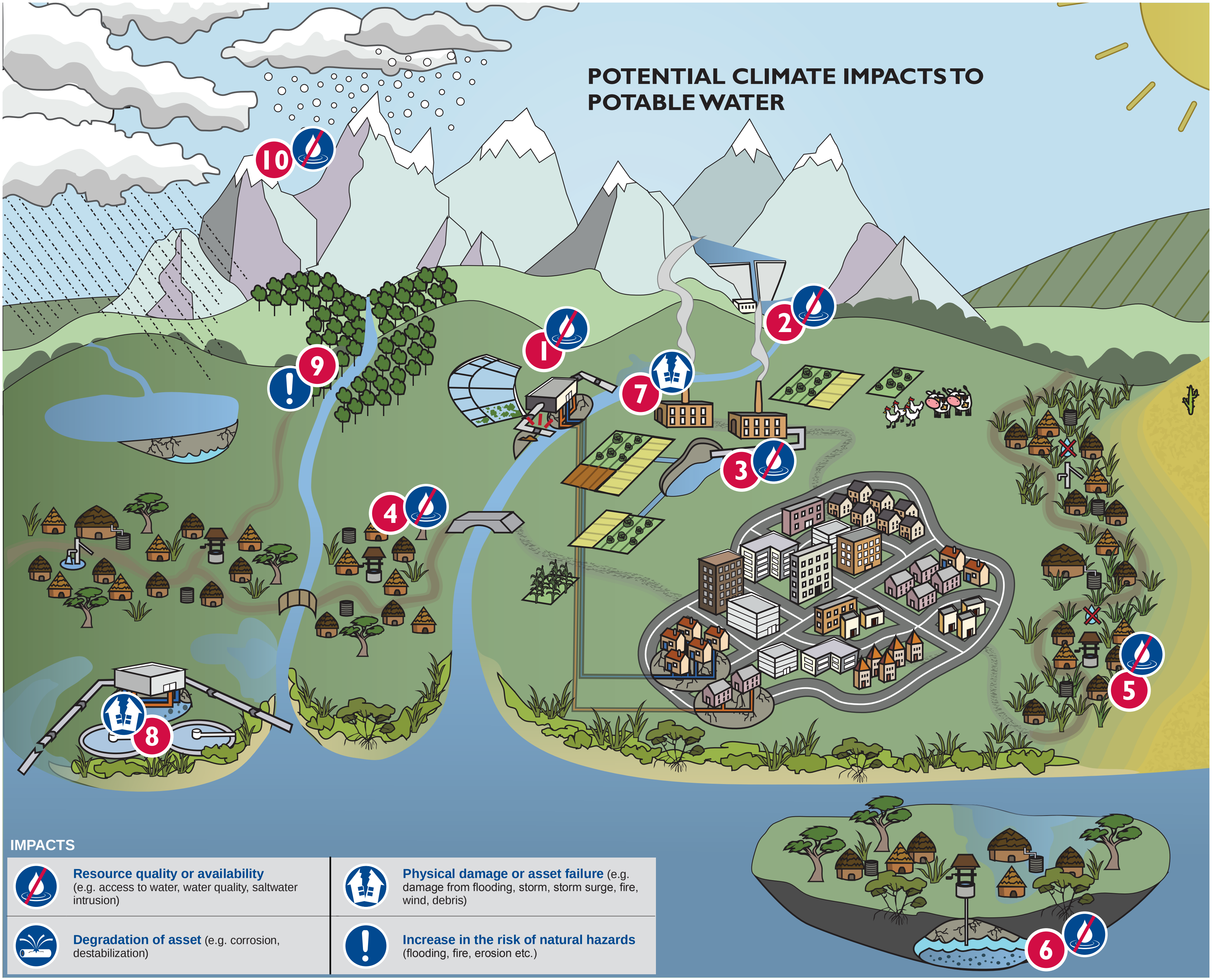
# POTENTIAL CLIMATE IMPACTS TO POTABLE WATER



## 1 Increased temperatures and shifts in precipitation patterns

**Climate Change Impact**
Reduced water quality and increased erosion

**Consequence Risk**
Reduced water quality (algal blooms in open storage systems); increased treatment costs; physical damage to pipes and structures

**Vulnerable System**
Extraction and treatment

## 2 Increase in extreme precipitation

**Climate Change Impact**
Increase in levels of sediment and erosion

**Consequence Risk**
Decrease in water storage capacity and quality

**Vulnerable System**
Reservoirs and storage

## 3 More frequent drought conditions

**Climate Change Impact**
Increased evaporation, slower groundwater recharge

**Consequence Risk**
Increased water scarcity; reduced quality of water; increased treatment costs

**Vulnerable System**
Extraction and treatment

## 4 Increased variability of wet / dry spells

**Climate Change Impact**
Water restrictions

**Consequence Risk**
Need for additional storage facilities to capture water when it does rain (e.g., rain water tanks)

**Vulnerable System**
Extraction and storage

## 5 Decrease in precipitation and increase in temperatures

**Climate Change Impact**
Water scarcity and desertification

**Consequence Risk**
Decreased availability of water resources; abandonment of source

**Vulnerable System**
Extraction and conveyance

## 6 Sea level rise

**Climate Change Impact**
Saltwater intrusion into coastal aquifers and mixing of freshwater lens

**Consequence Risk**
Salination of groundwater; abandonment of source

**Vulnerable System**
Extraction and conveyance

## 7 Increase in extreme precipitation and extreme weather events

**Climate Change Impact**
Flooding and physical damage

**Consequence Risk**
Damage to infrastructure leading to mechanical failure

**Vulnerable System**
Treatment and distribution

## 8 Sea level rise and storm surge

**Climate Change Impact**
Flooding and physical damage

**Consequence Risk**
Damage (such as corrosion) to pipes and intake structures; contamination of systems

**Vulnerable System**
Treatment and distribution

## 9 Decrease in precipitation and increase in temperatures

**Climate Change Impact**
Increased frequency and intensity of wildfires

**Consequence Risk**
Reduced recharge of water storage associated with vegetation regrowth; reduced water quality associated with increased particulate matter from fires in catchments

**Vulnerable System**
Extraction, reservoirs and storage

## 10 Decrease in mean precipitation and increase in mean temperatures

**Climate Change Impact**
Change in timing and quantity of snow and ice cover

**Consequence Risk**
Change in peak flow, and magnitude of, fresh water sources

**Vulnerable System**
Extraction, reservoirs and storage

Extreme Heat/ Heatwaves
Drying Trend/ Drought
Extreme Precipitation/ Flooding
Storm Surge
Sea Level Rise
Damaging Storms (wind, lightning)
Wildfire

## TYPES OF WATER SUPPLY INFRASTRUCTURE SYSTEMS

For the purposes of this guide, water supply infrastructure systems are categorized as large-scale and small-scale.

### LARGE-SCALE WATER SYSTEMS

Large-scale water supply systems are usually managed and administered by private or public water utilities that provide a fee-based water supply service. They service large populations and tend to be found in urban areas. They require considerable capital investment to develop, larger operational costs to maintain, trained staff and specialized equipment. They often include the following components, each of which is described in the sections below: 1) water resources, extraction, intake and raw water storage; 2) water treatment facilities; 3) treated water storage and distribution networks; and 4) water demand and supply management.

#### WATER RESOURCES, EXTRACTION, INTAKE AND RAW WATER STORAGE

Surface water and groundwater are primary sources of potable water, and the interaction between them can play a key role in replenishing aquifers and maintaining the quality and quantity of water in rivers and water basins. Surface water resources are commonly viewed as the most reliable and accessible source, provided that water quality, water flow, and storage capacity are adequate to meet specific use requirements. Engineering design measures can be implemented to address these constraints, such as by altering the intake location upstream of densely populated areas, or chemical treatment to minimize or remove contaminants.

Lakes are natural water storage reservoirs supplied by rivers, streams, and precipitation. Artificial reservoirs are created through the construction of dams across rivers and streams. Their storage capacity can provide protection from flooding to downstream environments during heavy rainfall, provided the reservoir has adequate capacity. This can be a major constraint if changing precipitation patterns cause more intense flooding over time.

Groundwater reservoirs provide natural storage systems for high quality water resources, and the use of groundwater reserves can eliminate costs for storage tanks and basins in the development of a water supply system. In addition, groundwater is often readily available at the point of demand, thereby reducing transmission and distribution costs for end consumers. Although groundwater supplies are less susceptible to seasonal changes in climate and are largely protected from pollution, the major constraint associated with groundwater quality is the potential for contamination from industrial, agricultural, or hazardous waste operations or through naturally occurring contaminants such as arsenic. Treatment options are available to improve groundwater in these instances, but water treatment will require higher capital expenditure (CAPEX) and operational expenditure (OPEX).

Potential climate change impacts and consequent risks to water resources and infrastructure associated with extraction and storage facilities include the following:

- ***Reduction in surface water and groundwater availability for large-scale potable water systems.*** Direct changes in precipitation patterns and indirect changes in land use or non-climatic stressors within the catchment can negatively impact water resource availability.

  Associated adaptation measures require appropriate location and sizing of large-scale potable water systems. Changes in the seasonality of precipitation patterns also require careful consideration, especially in regions with already marked seasonal climate patterns, such as tropical and sub-tropical areas and mountainous areas, as they could result in more intense and longer lasting seasonal water shortages. This would likely have an adverse impact on the reliable yields from surface water reservoirs. In addition, the potential for more extreme flood events may make spillway design options more expensive. Finally, evaporation losses from surface water reservoirs may be expected to increase as temperatures increase, thereby further reducing yields.

- ***Decrease in water quality.*** Multiple climate-influenced factors can negatively impact water quality in a variety of ways, including increased siltation, algal blooms, and decreased capacity for dilution of water contaminants. This can be particularly important when selecting sites for water extraction. Changes in water quality can also hinder treatment processes and require more rigorous measures. Increased salinity and reduced precipitation may impact shallow aquifers or reduce surface water dilution of salinity, impacting potable water supplies, irrigation water, or infrastructure longevity (e.g., building foundations). Increased saline intrusion is also associated with climate change, especially in coastal areas affected by sea level rise.

- ***Salinization of freshwater lenses.*** Small volcanic or coral quays often have a lens of freshwater floating on a transition zone of brackish water that lies on top of saltwater. Pumping from a freshwater lens may cause it to shrink and allow saltwater or brackish water to permeate the freshwater lens. The degree of saltwater intrusion depends on several factors, including the hydraulic properties of the geology, recharge rate, pumping rate, and well location. Expected climate change impacts such as sea level rise and changes in tropical cyclone patterns may exacerbate the risks to freshwater lenses due to salinization.

- ***Change in snow, glacial and rain cycles.*** Rising temperatures and changes in precipitation can significantly alter the hydrology pattern in mountainous areas as the thawing period lengthens and the snow line retreats to higher elevations. Short-term impacts due to snow melt could be beneficial as water resource availability temporarily increases, but long-term negative impacts can be more significant once existing ice reserves and snow pack have disappeared.
- ***Change in water extraction capability.*** Prolonged drought can cause water levels to drop significantly, either temporarily or permanently, thereby affecting the capability of water extraction measures designed to withdraw groundwater at specific depths. The water extraction area could also be impacted by increased salinity either as a result of sea level rise or storm surge.

**WATER TREATMENT FACILITIES**

Water treatment is a vital prerequisite for using many potable water sources. Water quality is measured by a number of different physical (turbidity, taste, odor, etc.), chemical, microbiological, and radiological parameters, for which there are various treatment options. The cost-effectiveness of each of the following treatment option's ability to remove contaminants should be evaluated:

- ***Aeration.*** Aeration is a natural process that occurs when water is brought into contact with air. Contaminants such as iron and manganese react with oxygen in the air, forming insoluble compounds that can be removed through subsequent treatment phases such as sedimentation or flocculation. The process of aeration is often accelerated by mixing or dispersing air through the water.
- ***Coagulation and flocculation.*** Coagulation and flocculation require the addition of chemical coagulants to the water in order to bind contaminants and form particles, which are then removed by settling, filtration or floatation. This process is primarily used to remove fine particles that cause turbidity and color.

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- ***Sedimentation.*** Sedimentation is the process by which suspended particles are allowed to settle in still or slow moving water. Suspended particles settle to the bottom of the tank and form a sludge layer, which is removed on a regular basis.

- ***Multi-stage filtration.*** Multi-stage filtration involves a combination of coarse gravel filtration followed by slow sand filtration to remove coarse and fine particulates, respectively. This process is a robust and reliable treatment method, which can remove considerable levels of contaminants, and is considered suitable for implementation in small or rural communities in developing countries, especially compared with more technical chemical treatment options.

- ***Rapid filtration.*** Rapid filtration is the process by which water is passed through sand or a similar coarse medium to remove contaminants, and is often coupled with the use of aeration to accelerate the process. Subsequent backwashing with clean water then removes contaminants from the filter bed.

- ***Disinfection.*** The final stage of water treatment is disinfection, which involves the addition of chemicals such as chlorine or ozone to reduce the number of pathogenic organisms to acceptable levels so they will not cause disease. Disinfection is only effective once previous stages of treatment have removed the majority of contaminants.

Potential climate change impacts and associated risks to water treatment infrastructure include:

- ***Higher operating costs and increased stress on treatment system assets.*** Decreases in water quality (e.g., sediment load and contaminants) additional treatment and additional stress on existing infrastructure, which lead to higher maintenance costs and early asset renewal.

- ***Direct physical impacts on water treatment infrastructure.*** Changes in extreme event patterns can cause direct physical damage to water system infrastructure. For example, flooding can cause an increased risk of mechanical or electrical failure of treatment systems.

- ***Impacts on sewage treatment infrastructure.*** Sewage treatment plants and associated assets are often located as close as possible to the lowest elevation point in a drainage basin or sub-basin, thereby increasing exposure to flooding. Flooding can contaminate water resources and affect the operation of the sewage treatment plant. Coastal or small island sewage treatment plants may be at risk due to sea level rise.

### TREATED WATER STORAGE AND DISTRIBUTION NETWORKS

Treated water storage tanks or basins are typically used to supplement supply in periods of high demand during the daily cycle or during emergency events such as fires. They provide storage for treated water and range from small-scale tanks to large, lined storage basins. The primary constraint associated with treated water storage is that open air storage tanks and basins can be subject to evaporative losses and exposed to potential contamination.

Water distribution systems transport water from the source or treatment facility to the end users. Distribution systems typically comprise a series of pipes in either branched or loop-grid configurations, connected to a main supply.

Branched systems are better suited for smaller communities with lower capacity water sources. They are easily designed because flow rates can be readily determined for each section of pipe. Constraints associated with branched systems include reduced reliability, where damage or leakage in one section of pipeline can impact other users downstream, a high potential for contamination and pollution, as well as sedimentation from low flow at the ends of the system. Branched systems may also experience large pressure variations as a result of fluctuating demand.

Looped systems are connected in a series of loops or grid configurations and therefore inherently require more complex design. They provide improved hydraulics, with the ability to separate the mains for maintenance and repair while still maintaining some level of supply to end users. Looped systems are primarily used to service larger urban areas, where distribution to a large number of water users is required at a reasonably low cost.

Potential climate change impacts and consequent risks to treated water storage and distribution networks include the following:

- ***Increased ground movements and damages to buried assets.*** For certain types of soils such as clay-based soils, climatic changes can be damaging to buried assets. Increased frequency of alternatives cycles (wet and dry, and hot and cold) and more intense floods and droughts are likely to alter soil and rock conditions and result in damages to buried assets (such as piping, lining of large reservoirs, etc.). This can be a significant risk for water utilities and result in leaks and higher repair costs. This risk manifests both through cracking of the buried piping systems

transporting treated water as well as damages to the lining of storage basins.

- ***Increased rate of evaporation.*** Evaporation results in loss of stored treated water in open air basins. As a direct consequence of increased air temperature, evaporation rates are likely to increase in many parts of the world resulting in greater losses.

### WATER DEMAND AND SUPPLY MANAGEMENT

Sound management of both water demand and supply is required to ensure the reliability, security, and sustainability of water resources to meet basic water and sanitation needs, as well as other domestic, industrial, agricultural, and environmental uses. Water demand and supply management for potable water should not be considered in isolation. A holistic approach to water resources is required in order to ensure sustainable management of water resources.

Water supply management refers to the provision of water from a water source to the end user via a distribution network of pipes and pumps, and the management of such systems by public utilities or other such organizations.

The management of water supply involves ensuring the security of supply by improving the efficiency of current water sources, reducing losses at the intake, and through the sourcing new water resources to supplement supply where required.

Demand side management involves the management of water at the end user. Common methods of demand management seek to increase water use efficiency and include water policy development and regulation, metering and tariffs, water restrictions, water reuse and recycling, and the promotion of water-saving technologies. In various parts of the world these measures have been very successful in significantly reducing water demand.

A number of issues affect water demand and supply management, including impacts on water availability and quality, changes in consumption, urbanization and industrialization pressures, conflicts of interest between water users, water losses, and increasing population demand on finite water resources.

Potential climate change impacts and consequent risks affecting approaches to water demand and supply management include the following:

- ***Increased demand reducing service levels.*** Future water demand is likely to be higher than current levels due to population growth and increasing per capita demand and to a lesser extent because of climate change. For instance higher temperatures and frequency of heat waves will likely lead to higher water consumption. This could lead to assets not meeting their level of service standards and adding stress to existing networks.
- ***Increased demand leading to increased resources competition.*** Climate change and demographic expansion are likely to result in increased water demand and conflicts between different end use, including environmental flows, domestic, industrial, and agricultural water usage.

## SMALL-SCALE WATER SYSTEMS

Small-scale water systems are usually managed locally (rather than by water utilities) and supply smaller populations, ranging from villages to clusters or communities of households, and are often more relevant to rural areas. They do not require extensive capital and maintenance costs and can often be built and maintained with local materials and basic technical skills. They can include rainwater harvesting, boreholes, wells, and direct extraction from rivers and water bodies.

### RAINWATER HARVESTING

Interest in rainwater harvesting systems has rapidly increased over the past three decades. This is particularly the case in rural areas of developing countries, where the funding required for piped water systems may be less available and small-scale projects are encouraged with support and involvement of non-governmental organizations, charities, community groups, and individual households. Every rainwater catchment system consists of: 1) a catchment surface to collect the rainwater; 2) a storage reservoir to store the water until required; 3) a delivery system to transport the water from the catchment surface to the reservoir (e.g., gutters or drains); and 4) an extraction device to release the water from the reservoir such as a tap, rope and bucket or pump. Roofs are the most common type of catchment surface for harvesting rainfall and they are widely used for individual household and domestic purposes. The main constraints are the size and type of the roof and the potential contamination of the collected water by the materials used to cover the roof and line the storage reservoir.

Major potential climate change impacts and consequent risks to rainwater harvesting systems are caused by changes in precipitation patterns. Altered rainfall patterns have direct impacts on rainwater harvest capacity, with potentially severe impacts on households and communities that may rely on rainwater for some or all periods throughout the year.

### BOREHOLES

Boreholes are often used where the water table is too deep for hand-dug wells. They are installed using drilling or auguring techniques and can be constructed to depths of over 200 meters depending on the ground conditions and the drilling methods used. Groundwater sourced from boreholes is generally of high drinking water quality and can be easily protected from contamination. The main constraint arises from the cumulative effect of multiple boreholes drawing from the same water source (i.e. an aquifer). Where the cumulative rate of extraction exceeds the rate of aquifer recharge, water users experience a draw-down effect and lowering of the water table. This can create competing demands between stakeholders, such as between urban and agricultural water users.

### WELLS

Water extraction from wells, particularly hand-dug wells, is the most common method of accessing groundwater resources in rural areas of developing countries. Wells typically range in depth from 5 to over 20 meters . Various methods can be used to excavate wells and the walls of a well shaft can be lined with different materials depending on availability, such as concrete, masonry or brickwork. A bucket and rope can be used to extract water but a hand pump is usually preferred. Constraints to

using well systems, particularly hand-dug wells, stem from soil suitability (e.g., clays and sand as opposed to rock) and the depth of the water table. While issues associated with water quality may arise, simple measures such as using a concrete cover slab, can aid in preventing pollution and contamination of the well.

#### DIRECT EXTRACTION FROM SURFACE WATER RESOURCES

Surface water extraction from rivers or lakes is often the most convenient source of water. Surface water extraction typically consists of a source such as a river or lake; a pipeline to transport the water from the catchment surface to the reservoir; tanks to store the water; and an extraction device such as a tap, rope and bucket, or pump to release the water from the reservoir. A major constraint associated with surface water resources is the high capital cost associated with pipelines required to transport the water from the source to the storage tanks and customers. Attention should also be given to the placement of water intakes to maximize the effect of gravity where possible to avoid the cost of pumps and reduce operational and maintenance costs. Depth should be considered in terms of reliability and security of supply, as well as water quality. Water quality must be monitored on a regular basis, and treatment may range from simple debris removal to more costly chemical treatment.

Potential climate change impacts and consequent risks to boreholes, wells, and direct extraction systems include the following:

- ***Reduced effectiveness of water extraction points.*** Water levels could drop significantly (either temporarily or permanently), which can in turn lead to the extraction point being above water level (and therefore ineffective). The water extraction area could also be impacted by increased salinity from sea level rise or storm surge.

- ***Reduction in surface water and groundwater resource availability.*** Direct changes in precipitation patterns and indirect changes within the catchment (including land use and non-climatic stressors) could result in a decrease in water resource availability. This type of risk would need to be considered in the location and sizing of large scale potable water systems. Changes in the seasonality of precipitation patterns should also be reviewed, particularly in regions such as tropical and sub-tropical areas and mountainous areas with already marked seasonal climate patterns that could result in more intense and longer lasting seasonal shortages.

## CLIMATE CHANGE IMPACTS AND RISKS

The connection between infrastructure planning and climate change adaptation are strong. Practitioners need to understand that climate change impacts on built assets and the resulting risks in order to make appropriate engineering design decisions.

Table 2 summarizes potential climate impacts posed by a range of climate stressors and their effects, and the consequent risks to water supply systems and infrastructure. These examples are not intended to provide an exhaustive catalogue of all possible climate impacts or adaptation options. What this table presents is an illustration of potential impacts to inform further analysis and adaptation planning.

**Prolonged drought can cause water levels to drop significantly, either temporarily or permanently, thereby affecting the capability of water extraction measures**

**TABLE 2: 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<br>• 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<br>• Increased treatment costs |
| Higher intensity storms | • Physical damage to structures; potential flooding<br>• 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 |

## TABLE 2: WATER SUPPLY INFRASTRUCTURE (continued)

| Climate Drivers | Impacts and Consequent Risks |
|---|---|
| **Reservoirs and Storage** | |
| More frequent drought conditions, increased evaporation | • Decreased availability of water resources<br>• 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<br>• 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<br>• 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<br>• Increased demand for urban and industrial water supplies may result in reduced availability of water for irrigation |

**Climate change can have a variety of impacts on surface water, drinking water, and groundwater quality.**


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CHAPTER 3

# A CLIMATE RESILIENT INFRASTRUCTURE METHODOLOGY

## ENABLING CLIMATE RESILIENT PLANNING AND DESIGN OF POTABLE WATER INFRASTRUCTURE

This chapter provides a step-wise methodology to enable practitioners to include climate change considerations in the design of new potable water structures or the evaluation of existing ones (see Figure 2).

- **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.

## STEPWISE APPROACH FOR CLIMATE RESILIENT INFRASTRUCTURE PLANNING AND DESIGN

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

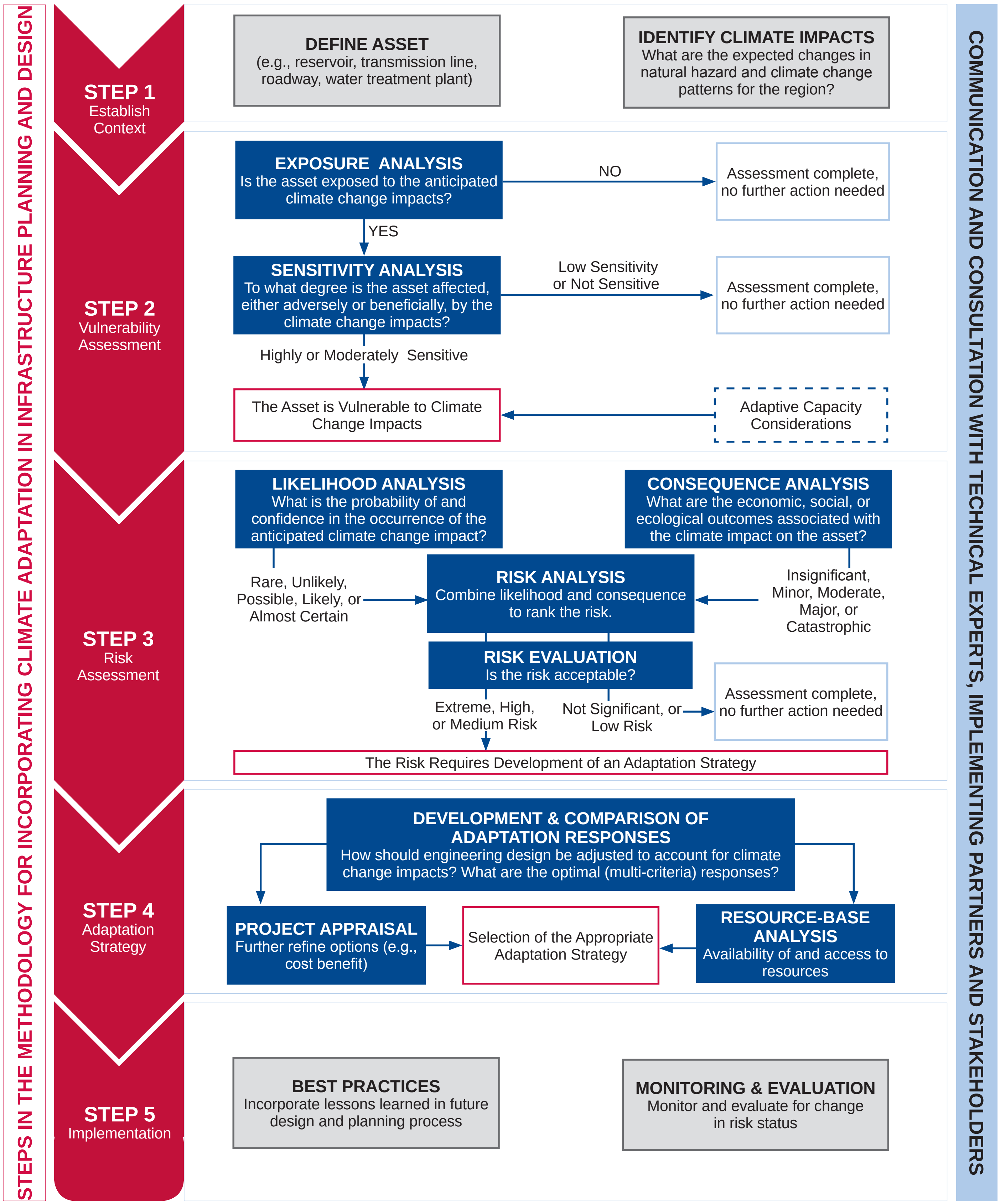
### 5 STEP PROCESS

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

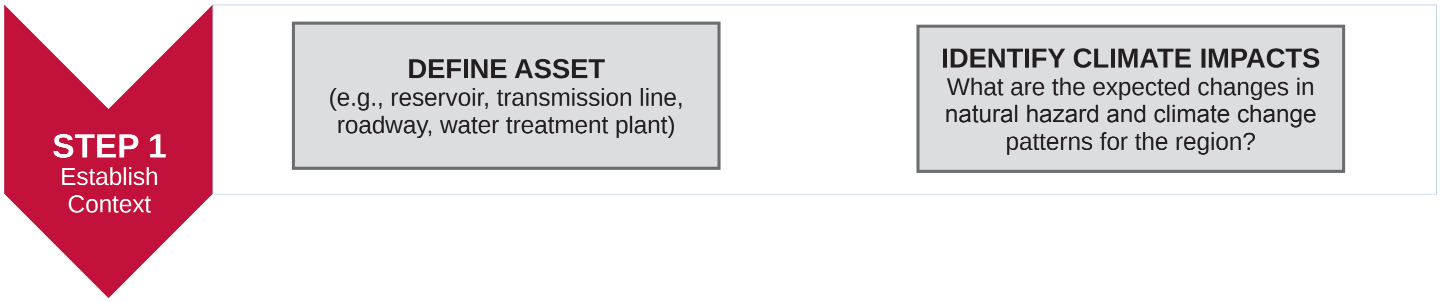
Collectively, these steps establish a climate resilient design methodology to be used when determining appropriate engineering design actions for more climate resilient structures.

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.

## FIGURE 2: USAID'S CLIMATE-RESILIENT DEVELOPMENT FRAMEWORK



## 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. Establishing the context notably includes defining the service to be delivered by the water supply infrastructure, and identifying the sources to be tapped within the context of future climate change.

### DEFINING INFRASTRUCTURE OBJECTIVES

For potable water infrastructure, it is important to review the likely future per-capita service requirements. 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 change accordingly.

Consideration should also be given to the broader system that the assets are integrated with. Once the scope of the assets are defined, information about the assets are needed 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 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. The USAID *Overarching Guide: A Methodology for Incorporating Climate Change Adaptation in Infrastructure Planning and Design* contains additional information and guidance on climate data and trends as well as information sources that may assist with this step.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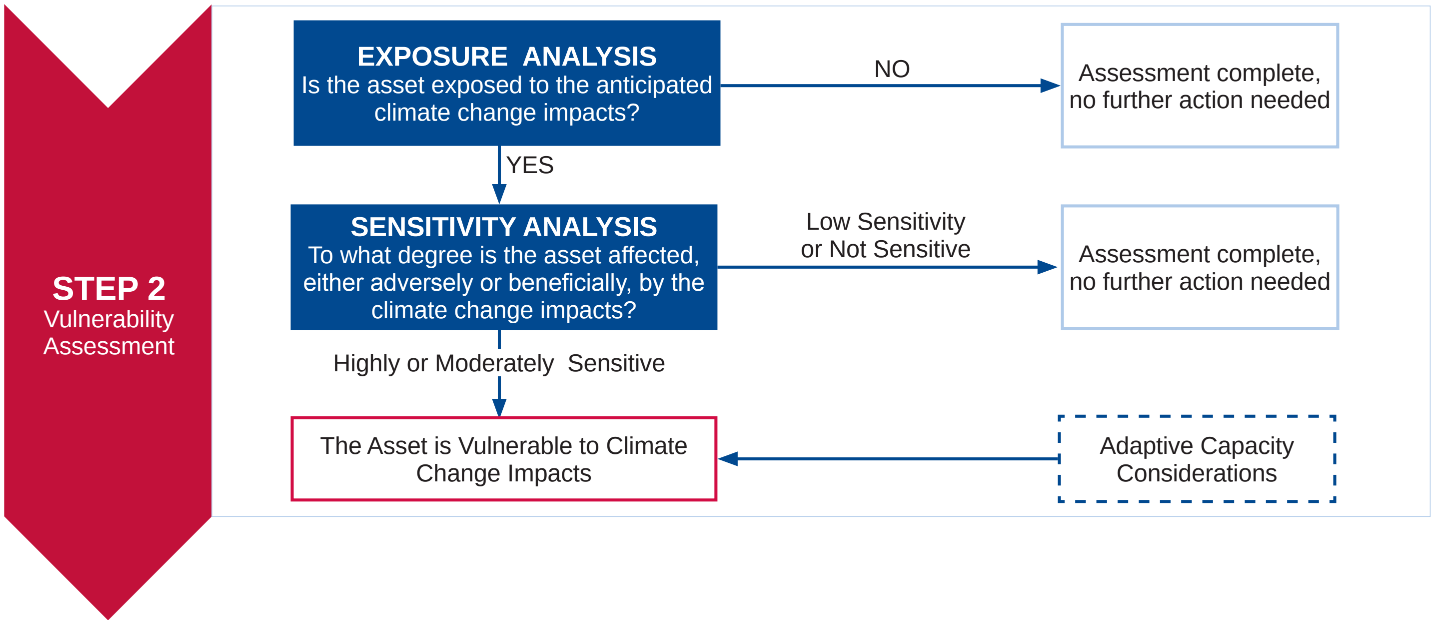
## STEP 2: VULNERABILITY ASSESSMENT




## 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. The 2014 USAID publication *Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change* 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 water 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 to particular climate change impacts identified in Step 1 should progress to the assessment of sensitivity. If an asset or project site is not exposed to climate change 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 water 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 3 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 4 provides a summary of the likely sensitivity of different types of infrastructure to different climate hazards.

**TABLE 3: 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<br>• Some minor restoration work required |
| **MODERATE Sensitivity** | • Widespread infrastructure damage and service disruption requiring moderate repairs<br>• 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.**


## ASSESSING ADAPTIVE CAPACITY

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.

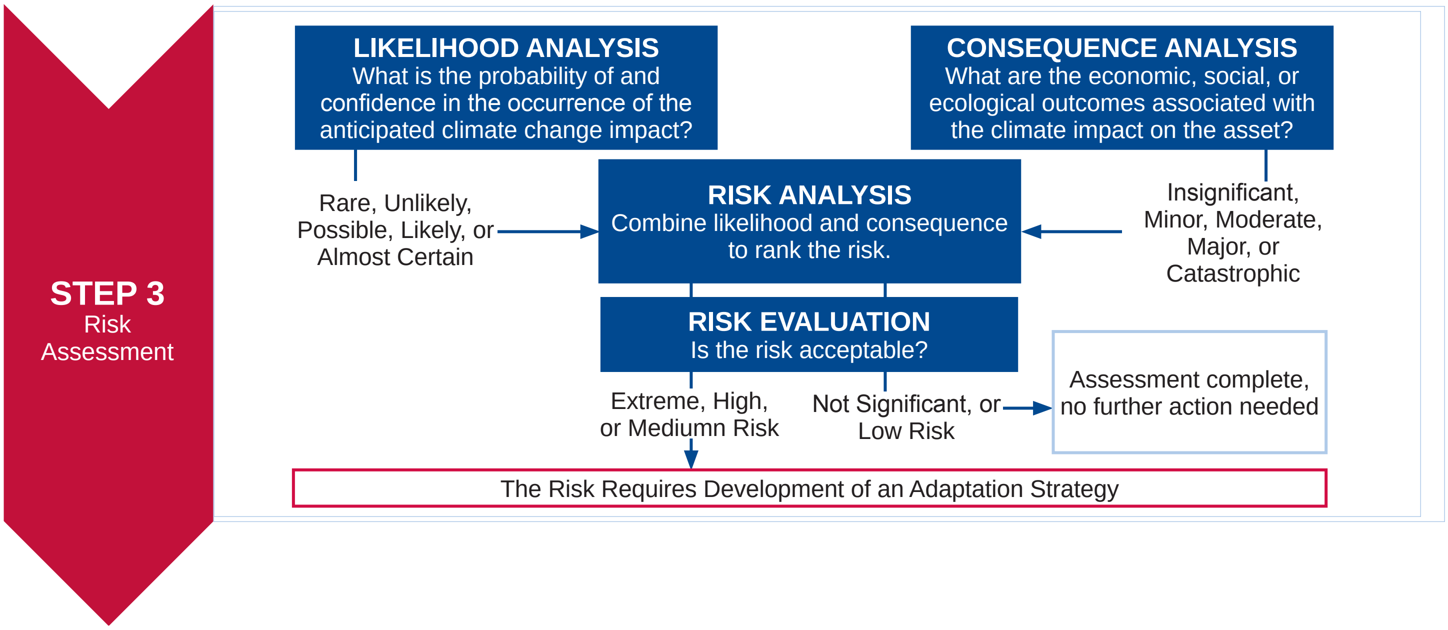
From a system perspective, this may be assessed by looking at core economic drivers in-country (or in similar contexts if not readily available), such as access to health services and education, resource strength in terms of wealth and human, strength of networks, institutions leadership, and disaster 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.

## TABLE 4: LIKELY SENSITIVITY TO CLIMATE CHANGE IMPACTS

| THEME | PROJECT | Extreme Heat | Drying Trend/ Dought | Extreme Precipi-tation/ Flooding | Storm Surge | Sea Level Rise | Damaging Storms (wind, lightning, snow/ice) | Wildfire |
|---|---|---|---|---|---|---|---|---|
| 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

## 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 risks once the vulnerability of an asset or project has been established. 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 of it occurring:

**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.

## LIKELIHOOD OF CLIMATE IMPACTS

Table 5 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 5: EXAMPLE OF 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 |

## 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, including different definitions of consequences for its water treatment, water storage, and distribution assets. Defining consequences is ideally done in a workshop setting with 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 6 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.
- **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 6: EXAMPLE DESCRIPTOR FOR CONSEQUENCES**

| Level of Likelihood | | Definition |
|---|---|---|
| 5 | Catastrophic | • **Asset Damage:** Permanent damage and / or loss of infrastructure.<br>• **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.<br>• **Financial Loss:** Asset damage > annual maintenance budget or 75% of CAPEX value.<br>• **Health / Safety:** Substantial changes to the health and safety profile; risk of multiple fatalities as a result of extreme events.<br>• **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.<br>• **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.<br>• **Financial Loss:** Asset damage 50%+ of annual maintenance budget or 25% of CAPEX value.<br>• **Health / Safety:** Marked changes in the health and safety profile, risk of severe injuries and even fatality as a result of extreme events.<br>• **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.<br>• **Loss of Service:** Widespread interruption of service for less than 20% of the agreed Level of Service; result in minor contractual penalties.<br>• **Financial Loss:** Asset damage > 10% but < 25% of annual maintenance budget or 5% of CAPEX value.<br>• **Health / Safety:** Noticeable changes to the health and safety profile, risk of severe injuries as a result of extreme events.<br>• **Reputation:** Adverse news in media / Significant community reaction. |
| 2 | Minor | • **Asset Damage:** No permanent damage / Some minor restoration work required.<br>• **Loss of Service:** Localized interruption of service for less than 10% of the agreed Level of Service.<br>• **Financial Loss:** Asset damage > 5% but < 10% of annual maintenance budget or 1% of CAPEX value.<br>• **Health / Safety:** Slight changes to the health and safety profile; risk of minor injuries as a result of extreme events.<br>• **Reputation:** Some adverse news in the local media / Some adverse reactions in the community. |
| 1 | Insignificant | • **Asset Damage:** No infrastructure damage.<br>• **Loss of Service:** Localized interruption of service for less than 1% of the agreed Level of Service (LoS).<br>• **Financial Loss:** Asset damage < 5% of annual maintenance budget or negligible CAPEX value.<br>• **Health / Safety:** Negligible or no changes to the health and safety profile or fatalities as a result of extreme events.<br>• **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 7).

**TABLE 7: 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 8: EXAMPLE RESPONSES AND ACCEPTABILITY FOR DIFFERENT LEVELS OF RISK**

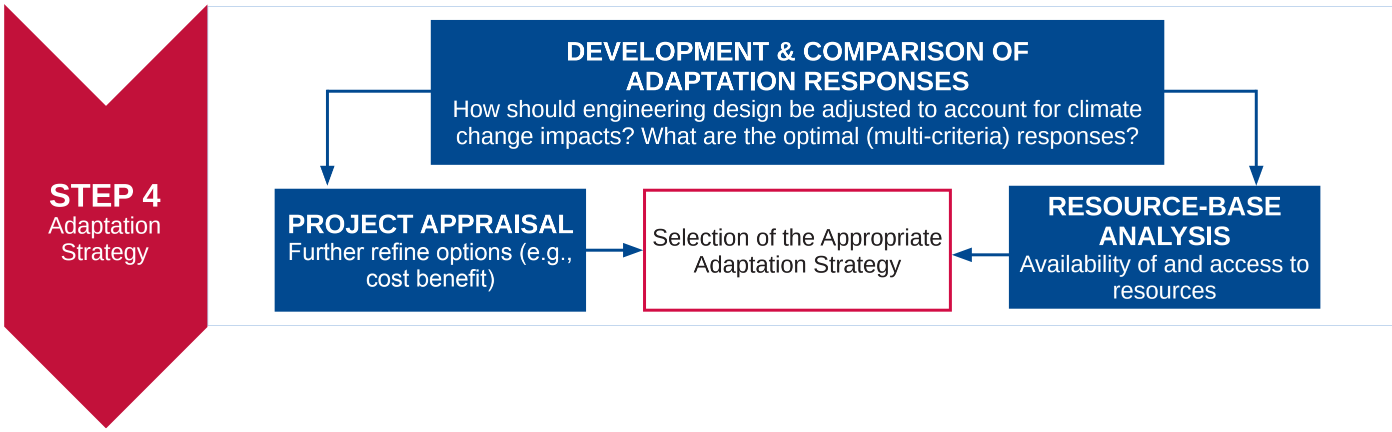
| Level of Risk | Definition |
|---|---|
| **EXTREME** ≥ 20 | • Extreme risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations<br>• These risks are not acceptable without treatment |
| **HIGH** 12-16 | • High risks are the most severe that 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<br>• 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<br>• 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<br>• 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 8) 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.

# 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 be made regarding how to address the risks. A range of appropriate 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 to no resources use (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. These strategies can help categorize various adaptation responses for new and existing infrastructure (Table 9) and understand the various advantages and disadvantages of selected responses (Table 10).

Examples of adaptive engineering design options specific to potable water infrastructure are provided in Table 11, with additional detail provided in the Annex.

### SHORT-LISTING OF ADAPTATION SOLUTIONS

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. An example of a completed MCA is included in the companion document: *Overarching Guide: A Methodology for Incorporating Climate Change Adaptation in Infrastructure Planning and Design*.

## TABLE 9: APPROACH TO ADAPTATION STRATEGIES

| Strategic Approach | | Adaptation Strategy | |
|---|---|---|---|
| | | Existing Infrastructure | New Infrastructure |
| 1 | Accommodate and Maintain | • Extend, strengthen, repair or rehabilitate over time<br>• Adjust operation and maintenance | • Design and build to allow for future upgrades, extensions or regular repairs |
| 2 | Harden and Protect | • Rehabilitate and reinforce<br>• Add supportive or protective features<br>• Incorporate redundancy | • Use more resilient materials, construction methods, or design standards<br>• 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 |

## TABLE 10: ADVANTAGES AND DISADVANTAGES OF ADAPTATION APPROACHES

| Strategic Approach | | Advantages | Disadvantages |
|---|---|---|---|
| 1 | Accommodate and Maintain | • Less costly<br>• 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<br>• Necessitates design for more flexible or upgradeable structure |
| 2 | Harden and Protect | • Proactive<br>• Straightforward to implement and justify | • More costly<br>• Assumes reasonably accurate climate forecasts |
| 3 | Relocate | • Proactive | • More costly<br>• 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 |

## TABLE 11: EXAMPLES OF ADAPTATION OPTIONS FOR CLIMATE RESILIENT POTABLE WATER INFRASTRUCTURE

| | | |
|---|---|---|
|    | Drought, Reduced Average Precipitation, Increased Surface Water Temperature, Wildfires | • Increase the individual capacity and the number of rainwater tanks<br>• Relocation of raw water intake<br>• 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<br>• Consider alternative water supply options (e.g. recycled water systems) and conservation measures (e.g. restrictions on water use)<br>• Asses the utility's flexibility to switch between different water sources<br>• Implement water metering and tariff management to reduce water consumption<br>• On-site recycling of used water or decentralized treatment and non-potable reuse<br>• Maintain and implement vegetation management practices that aim to minimize fire risk |
|   | Extreme Precipitation Events, Less frequent but higher intensity storms, Flooding | • Increase carrying capacity of stormwater drainage and the storage capacity stormwater treatment systems to include future precipitation projections<br>• Stabilize landslide-prone area, slopes, embankments<br>• Elevate mechanical and electrical equipment in operations or maintenance facilities<br>• Implement Water Sensitive Urban Design strategies for stormwater management and replenishment of groundwater resources |
|   | Sea Level Rise and Storm Surge | • Raise elevation of storage infrastructure to protect from saltwater intrusion<br>• Elevate mechanical and electrical equipment in operations or maintenance facilities<br>• Increase capacity of stormwater drainage system and increase drainage maintenance<br>• Use corrosion-resistant or waterproof materials<br>• Promote the use of surface water and groundwater resources, including salinity and flow barriers and improved management of groundwater extractions |

## STEP 5: IMPLEMENTATION

**STEP 5**
Implementation

**BEST PRACTICES**
Incorporate lessons learned in future design processes

**MONITORING & EVALUATION**
Monitor and evaluate for change in risk status

## 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 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.

Mozambique

DeNatale, AECOM


Community consultation, Helmand Afganistan

# SUGGESTED RESOURCES

## Guidelines for Water Supply and Sanitation Programs

American Public Health Association (APHA). 2012. Standard Methods for the Examination of Water and Wastewater, 22nd Ed. Washington, D.C.: APHA, available at http://www.standardmethods.org

IWMI. 2009. Flexible water storage options: for adaptation to climate change. Colombo, Sri Lanka: International Water Management Institute (IWMI). 5p. (IWMI Water Policy Brief 31), available at http://www.iwmi.cgiar.org/

National Institute of Standards and Technology (NIST). 2015. Community Resilience Planning Guide for Buildings and Infrastructure Systems (Draft for Public Comment – April 2015) http://www.nist.gov/el/building_materials/resilience/guide.cfm

OECD. 2009. Private Sector Participation in Water Infrastructure: OECD Checklist for Public Action, available at http://www.oecd.org/daf/inv/investmentfordevelopment/privatesectorparticipationinwaterinfrastructureoecdchecklistforpublicaction.htm

U.S. Environment Protection Agency. 2015. Adaptation Strategies Guide for Water Utilities (CRWU) http://water.epa.gov/infrastructure/watersecurity/climate/index.cfm

Warner. D, Abate, C. July 2005. Guidelines for the Development of Small-scale Rural Water Supply & Sanitation Projects in East Africa, available at http://www.encapafrica.org/documents/Wat0509_e.pdf

World Health Organization and UNICEF. 2012. Progress on Drinking Water and Sanitation 2012 Update, available at http://whqlibdoc.who.int/publications/2012/9789280646320_eng_full_text.pdf

World Health Organization. 2012. UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water, available at http://whqlibdoc.who.int/publications/2012/9789241503365_eng.pdf

World Health Organization. 2012. Water for Health: WHO guidelines for drinking-water quality (2012), available at http://www.who.int/water_sanitation_health/WHS_WWD2010_guidelines_2010_6_en.pdf

## Raw Water Supply

World Commission on Dams (WCD). 2000. Dams and Development: A Framework for Decision-Making, available at http://www.internationalrivers.org/campaigns/the-world-commission-on-dams

## Rainwater Harvesting

Lancaster, B. 2012. Rainwater Harvesting for Drylands and Beyond. Financial Incentives & Resources, available at http://www.harvestingrainwater.com/rainwater-harvesting-inforesources/water-harvesting-tax-credits

Sustainable Innovations USA (SI-USA). 2012. Aakash Ganga, River from Sky, available at http://si-usa.org/projects/rainwater-harvesting

United Nations Development Programme (UNDP). Examples of Successful Experiences in Providing Safe Drinking Water-Roof top Rain Harvesting, India: Sharing Innovative Experiences. 11 (1) Chapter 4, available at http://tcdc2.undp.org/GSSDAcademy/SIE/Docs/Vol11/SIE.v11_CH4.pdf

UNEP. 2009. Rainwater harvesting: a lifeline for human well-being. report prepared for UNEP by Stockholm Environment Institute

UNWAC. 2011. Rainwater Harvesting and Utilisation. Blue Drop Series. 1 (1), available at http://www.unwac.org/new_unwac/pdf/WATSAN_Normative_Pubs/Blue_Drop_Series_01_-_Policy_Makers.pdf

USEPA. 2013. Rainwater harvesting: conservation, credit, codes and cost – literature review and case studies

## Water Treatment Measures

Bloom and XPV capital. 2010. Natural Systems Utilities, Middlesex Water, And Village Of Ridgewood Receive Environmental Achievement Award – Press release, available at http://www.xpvcapital.com/wp-content/uploads/Environmental-Achievement-Award-November-13-2012.pdf

## Demand Management

Farley, M., G. Wyeth, Z. Ghazali, A. Istandar, and S. Singh. 2008. The Manager's Non-revenue Water Handbook. A Guide to Understanding Water losses. Published by Ranhill Utilities Berhad and the United States Agency for International Development (USAID) in association with AECOM, available at http://warrington.ufl.edu/centers/purc/docs/resources_NRWManagersHandbook.pdf

World Bank. 2006. The Challenge of Reducing Non-Revenue Water in Developing Countries How the Private Sector Can Help: A Look at Performance-Based Service Contracting. Water Supply and Sanitation sector board discussion paper series, available at http://siteresources.worldbank.org/INTWSS/Resources/WSS8fin4.pdf

## Water Sensitive Urban Design

Joint Steering for Water Sensitive Cities (JSCWSC). 2009. Evaluating Options for Water Sensitive Urban Design – a national guide, available at http://www.environment.gov.au/water/publications/urban/water-sensitive-design-national-guide.html

## Desalination

Freshwater, A. and Talagi, D. 2010. Desalination in Pacific Island Countries: A Preliminary Overview. SOPAC Technical Report 437, available at http://www.sopac.org/sopac/docs/SOPAC%20Technical%20Report%20437%20Desalination%20for%20Pacific%20Island%20Countries.pdf

International Renewable Energy Agency (IRENA). 2012. Water Desalination Using Renewable Energy: Technology Brief, available at http://www.irena.org/DocumentDownloads/Publications/Water_Desalination_Using_Renewable_Energy_-_Technology_Brief.pdf

McGrath, C. 2010. Renewable Desalination Market Analysis: Oceania, South Africa, Middle East & North Africa. Promotion of Renewable Energy for Water production through Desalination (Pro-Des) Project, Work Package 5, Task 5.4, Export Market Analysis. Aquamarine Power Limited, Scotland

Water Reuse Association. 2012. Seawater Desalination Costs - White Paper. Water Reuse Association Desalination Committee, available at http://www.watereuse.org

World Bank. 2012. Renewable Energy Desalination: An Emerging Solution to Close the Water Gap in the Middle East and North Africa. Washington, DC: World Bank. DOI: 10.1596/978-0-8213-8838-9. License: Creative Commons Attribution CC BY 3.0, available at http://water.worldbank.org

## Other Water Related Topics of Interest

Bloom and XPV capital. 2010. Natural Systems Utilities, Middlesex Water, And Village Of Ridgewood Receive Environmental Achievement Award – Press release, available at http://www.xpvcapital.com/wp-content/uploads/Environmental-Achievement-Award-November-13-2012.pdf

International Water Association. (IWA). 2008. Specialist Group on Climate Change, available at http://www.worldwatercouncil.org/fileadmin/world_water_council/documents_old/Library/Publications_and_reports/Climate_Change/PersPap_10._Water_Industry.pdf

Kohler T. and Maselli D. (eds) 2009. Mountains and Climate Change - From Understanding to Action. Published by Geographica Bernensia with the support of the Swiss Agency for Development and Cooperation (SDC), and an international team of contributors. Bern, available at http://www.cde.unibe.ch/userfiles/Fullversion_low_Mountains_and%20_Climate_Change.pdf

Leverenz, H.L. and T. Asano. 2011. Treatise on Water Science, Pages 63–71 Volume 4: Water-Quality Engineering. Wastewater Reclamation and Reuse System, University of California at Davis, CA, USA

Robinson, D.W. Construction and Operating Costs of Groundwater Pumps for Irrigation in the Riverine Plain. CSIRO, available at http://www.clw.csiro.au/publications/technical2002/tr20-02.pdf

## Websites

IRC International Water and Sanitation Centre, available at http://www.irc.nl

NETWAS: Network for Water and Sanitation. Hosting the International Training Network for Water and Waste Management (ITN - Africa), available at http://www.netwas.org

Water and Sanitation Program Knowledge Network, available at http://www.wsp.org

Water Supply and Sanitation Collaborative Council, available at http://www.wsscc.org

WELL Research Centre Network for Water, Sanitation and Environmental Health, available at http://www.lboro.ac.uk/well/


GETTY

## POTABLE WATER CLIMATE CHANGE ADAPTATION STRATEGIES

# ANNEX

This Annex, *Potable Water Climate Change Adaptation Strategies*, is a companion to *Potable Water: A Methodology for Incorporating Climate Change Adaptation in the Infrastructure Planning and Design*. More details, including the advantages and disadvantages of various adaptation strategies, are discussed in this document. Practitioners, engineers, and other stakeholders will find the components to develop a preliminary cost estimate that is valid for a proposed project. Other aspects, such as technical feasibility and schedule, are also discussed in this Annex.

There are many comprehensive solutions and adaptation options that address climate change. Some involve technology or innovative and detailed design, while others involve the use of different materials. All options have their advantages and disadvantages, for instance: concrete is less sensitive to climate change effects, but harder to maintain. Some adaptation options may involve a substantial one-time, capital expenditure (CAPEX), whereas a number of solutions require incremental increase in normal business operational expenditures (OPEX). Nonetheless, all strategies are intended to assist with decision-making for climate-proofing potable water infrastructure. The adaptation options relevant to the following potable water infrastructure subjects are included in this Annex: raw water supply, rainwater harvesting, water treatment facilities, water quality protection, water demand management strategies, and water sensitive urban design.

Climate change adaptation strategies are an evolving and dynamic domain, with best practices and as-built case study examples being refined across the globe in multiple environments and contexts. This Annex is not intended to be exhaustive. If there is a strategy or approach that you think merits more discussion in this Annex, please send your ideas to climateadapteddesign@usaid.gov. We would like to consider user comments and recommendations in our next revision.

# CONTENTS

## WATER SOURCES AND SUPPLY

Historically the predominant response to increasing water demand in developing countries has been to tap into more or alternative sources of raw water supply, in particular rivers and groundwater. Because of environmental concerns and limitations in the availability of water resources, including seasonal droughts that may result from climate change, in many cases this approach is now no longer feasible. In some areas local resources are already fully exploited, and the potential for additional extraction is greatly limited. However, supply-side management measures are often the first option pursued in response to water shortages.

### TABLE A.1: RAW WATER SUPPLY OPTION - RELOCATION OF RAW WATER INTAKE

| Overview | |
|---|---|
|  | Relocation of raw water intake may be required where the current source is no longer viable or prone to fluctuations in quality and quantity. While climate change is known to impact severity and frequency of droughts and floods, an outcome of this can also be an increase in salinity, turbidity, and algal blooms (IWA, 2008).Where runoff, erosion, and salinity cause a decrease in water quality at the point of extraction, it may be possible to move the point of intake upstream. This creates flexibility in extraction where systems can draw from each point in various ratios. At times of low water quantity it may be necessary to set an intake point at a lower depth to account for extreme low flow rates.<br>Relocation can be within the same water system such as upstream from current source, or tapping into a nearby alternate location such as a lake or groundwater supply. Infrastructure needed includes additional pipes and pumps depending on the distance from the original intake.<br>The same water treatment facilities, including the distribution network, can be utilized. |
| **Advantages** | • The existing potable water system, for treatment, storage and distribution can be retained<br>• Increased guarantee of supply, water security and water quality<br>• Flexibility in water sources |
| **Disadvantages** | • There might not be alternative locations for raw water intake<br>• Requires some CAPEX and extensive design and construction capabilities (might require external procurement)<br>• Some variability in the pattern of demand, e.g., irrigation water for agriculture is only required during certain times of the year (IWMI, 2009) |
| **Indicative Costs** | • Design and construction costs of relocation for small-scale pipe construction to large systems requiring new pumps |
| **Timing for Implementation** | • Relocation of raw water intakes can be achieved in less than 12 months for most systems and locations |
| **Governance** | • Relocation of raw water intake would require involvement from relevant water utilities and their engineering division or external procurement if they don’t have internal capacity. It does not require involvement from the general community |
| **Acceptability** | • High acceptability – usually it does not result in significant disturbance to local communities |
| **Feasibility and Technical Requirement** | • Relocating raw water intake is a common engineering practice and is well established. However, it does require specific engineering inputs for design and construction as well as relevant materials (i.e., not local materials)<br>• Existing local skills associated with current facilities can be used for operational purposes |

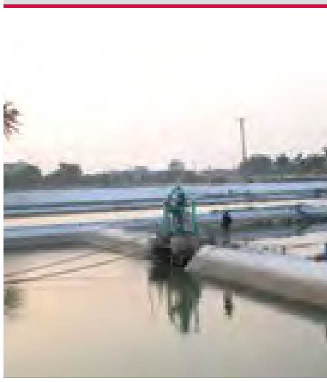
## TABLE A.2: RAW WATER SUPPLY OPTION - DIVERSIFICATION OF WATER RESOURCES

| Overview | |
|---|---|
| | Diversifying sources of water supply is likely to become increasingly important for water utilities. Given the expected impacts that climate change will have on water resources, reliance on a single source of supply may become an increasing risk for many urban water utilities. Existing water intake systems may not be adequate under climate change. The foreseeable increasing cost of water available for treatment and distribution may force utilities to assess alternative options. Options may include building 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. It will be particularly important to assess a utility's flexibility to switch between different water sources. Intake from each of these sources has different implications for required equipment, inputs (chemicals, electricity) and the technical capacity of a utility's staff and the impact on individual households. |
| **Advantages** | • Flexibility in water sources<br>• Increased guarantee of supply and water security<br>• Decrease stress on single point source |
| **Disadvantages** | • High CAPEX and additional OPEX associated with new infrastructure and source type<br>• There may be no additional locations for water sources |
| **Indicative Costs** | • For groundwater wells<br>• Pipelines between basins and relocation of source<br>• Storage capacity creation or enhancement |
| **Timing for Implementation** | • 2 months for small-scale pipe lines and wells<br>• 3 -10 years for large-scale storage facility construction |
| **Governance** | • Small infrastructural projects require local utility operators and CAPEX input for external materials needed<br>• Large projects for storage or tapping of groundwater requires public consultation of location of extraction and equity of distribution |
| **Acceptability** | • High acceptability where impact on local communities is low<br>• Conflicts arise where additional water source requires relocation or changes to local community structure |
| **Feasibility and Technical Requirement** | • Relocation of raw water, groundwater tapping and storage construction and enhancement are common engineering. Will require specific engineering inputs for design and construction as well as relevant materials (i.e., not local materials)<br>• Existing local operation and maintenance skills associated with current facilities can be limited. OPEX and operation and maintenance needed for new larger facilities |

## TABLE A.3: RAW WATER SUPPLY OPTION - EXPLORATION FOR GROUNDWATER RESOURCES

| Overview | |
|---|---|
|  | Groundwater will be impacted by climate change on a slower and more indirect basis compared to other water sources such as rivers. Rivers are replenished over shorter time scales, and directly reflect the impact of drought and flood events. Groundwater is affected at a much slower rate. Only after prolonged droughts will groundwater levels show declining trends. Recharging of groundwater aquifers also occurs over longer periods. Sustainable management of groundwater therefore requires the balance of extraction with recharge over longer timescales. Water scarce regions, such as Africa, are likely to incur further climate change related issues; however, a study by MacDonald et al. (2012, p1) indicates that “…groundwater is the largest and most widely distributed store of freshwater in Africa”.<br>Exploration includes key phases of preliminary and detailed surveys to discover:<br>• Identification of aquifers and their characteristics; and<br>• Identification of development methods (i.e., well type, depth, pumps) required.<br>The infrastructure required to harness groundwater depends on the characteristics of the source. Water lifting devices include wind, solar, motor or manual driven pumps and wells such as bores and spearpoints. |
| **Advantages** | • Supply of potable water without major treatment or storage needed<br>• Simple measures of extraction are available<br>• Compatible with existing infrastructure |
| **Disadvantages** | • Location of resource inconvenient or requires additional infrastructure to reach and then supply to users<br>• Some CAPEX and OPEX required, including operation and maintenance costs, and costs associated with monitoring for contamination<br>• Draw down impacts from over-extraction and the resulting depletion of shallow aquifers<br>• Potential for the mobilization of contamination and migration of poor water quality |
| **Indicative Costs** | • Substrate dependent for well drilling<br>• Large-scale groundwater project<br>• Shallow extraction<br>• Deep extraction |
| **Timing for Implementation** | • Exploration and monitoring over a few months depending on size<br>• Bore drilling approximately 30 meters per hour for hard rock<br>• Construction of pumps within a few weeks |
| **Governance** | • Relevant funding body and engineering units<br>• Public consultation over placement of pumps and wells |
| **Acceptability** | • Moderate to high level of acceptability as limited disturbance to community.<br>• Concerns regarding sustainability of resource and equity in distribution across users |
| **Feasibility and Technical Requirement** | • Requires moderate hydrogeological, engineering and construction management expertise (local and external procurement including international companies)<br>• Requires basic skills for operation and maintenance tasks, local training investment |

## TABLE A.4: RAW WATER SUPPLY OPTION - ENHANCING STORAGE CAPACITY

| Overview | |
|---|---|
|  | Construction of additional reservoirs to alleviate variability in seasonal, monthly, daily, and hourly water availability is one consideration for utilities that face water stress. Enhancing existing reservoir capacity is also an option for utilities facing increased variability in precipitation. Increasing capacity of reservoirs filled during the rainy seasons can be used to bridge shortfalls that may be encountered during dry periods.<br>The key difficulty reported for this option is in maintaining and securing agreements for pollution protected zones to ensure acceptable levels of water quality. Another consideration with this approach is that such reservoirs may affect property rights, and require land acquisition and resettlement of affected communities. If properly designed, these reservoirs have the capacity to bring substantial environmental benefits. In addition to increased stability in water supply, seasonal reservoirs can capture stormwater runoff and contribute to increased aquifer recharge. They can also mitigate the impact of downstream flooding. While the construction of new dams and reservoirs may be feasible for some utilities, they can only be built where suitable sites are available. |
| **Advantages** | • Enhancement of existing reservoirs requires less land use change and lowers environmental impacts<br>• Small increments in dam wall size can result in sizable yield increases<br>• Once built, reservoirs do not require additional energy input or resources<br>• Opportunities for power generation |
| **Disadvantages** | • Requires changes to surrounding land use and downstream environments, especially for new damn construction<br>• Limits to implementation; specific requirements for suitable sites<br>• Does not address immediate water needs; reliant on rainfall post construction to be beneficial<br>• Open water storage susceptible to increased evaporation as a result of climate change<br>• High CAPEX associated with the provision of new infrastructure |
| **Indicative Costs** | • Tens, to hundreds of millions of dollars (US) based on reservoir wall increases of between 5 -15 meters |
| **Timing for Implementation** | • 3-5 years construction for enhancement of existing reservoirs |
| **Governance** | • Investments from Public-Private Partnership to meet the required level of CAPEX and OPEX<br>• Needs level of public consultation relational to size of project and land change<br>• International guidelines for the construction and operation of large dams set by the World Commission on Dams (WCD, 2000) |
| **Acceptability** | • Opposition in terms of land use change, displacement and relocation of local people, negative impacts on surrounding environment (Level of Services of biodiversity by flooding the reservoir)<br>• Inappropriate construction and operation of past reservoirs, resulting in significant downstream social, economic and environmental impacts (IWMI, 2009)<br>• Large reservoirs are particularly controversial |
| **Feasibility and Technical Requirement** | • Requires extensive engineering and construction management expertise (most likely provided through external procurement including international companies) |

## TABLE A.5: RAW WATER SUPPLY OPTION - WATER REUSE

| Overview | |
|---|---|
|  | Reuse of reclaimed water is an increasingly common response to water scarcity in many parts of the developed world. Reclaimed water is being reused directly for various non-potable uses, including irrigation; commercial uses such as vehicle washing; industrial reuse such as cooling water, boiler water and process water; environmental and recreational uses such as the creation or restoration of wetlands; as well as agricultural irrigation and fire fighting.<br>Two levels of infrastructure exist, on site recycling of used water and decentralized treatment (industrial reuse, small local use):<br>• Satellite or centralized treatment facilities (dense population). The feasibility of this approach requires investment in treatment facilities and the ability to redirect water back through existing pipe systems; and<br>• Centralized systems are often viewed as uneconomic, making decentralized or on site facilities more viable (Leverenz & Asano, 2010).<br>Reclaimed water helps alleviate the stresses of access in times of scarcity. With more extreme variations between droughts and wet periods, this method of water recycling helps retain a sustainable level of extraction during low input times. On site reclamation also reduces costs associated with purchased water. The most inexpensive form of water treatment plants is the creation of wetlands and natural filtration areas which also improve other environmental issues. These are gaining popularity within the developing nations (Massoud et al. 2009). |
| **Advantages** | • Maximizes benefits gained from unit of water before moving downstream<br>• Conserves potable water supply for drinking<br>• Limits stress on water cycle |
| **Disadvantages** | • Location of treatment facilities and users may be large<br>• Health concerns and general public discontent<br>• Additional energy input for treatment and re-distribution<br>• High CAPEX and OPEX for centralized facilities |
| **Indicative Costs** | • Centralized system total capital cost<br>• Total operation cost<br>• Alternative decentralized gravity system total capital cost |
| **Timing for Implementation** | • 1 - 3 years for remodeling of existing system or creation of new treatment plant and pipes |
| **Governance** | • Business based models for recycled water do not require external input<br>• Public-Private coordination for large-scale reclamation schemes<br>• Utilities providers for approval and existing infrastructure<br>• Public consultation to improve acceptability, educate levels of use for quality |
| **Acceptability** | • Public disapproval based on quality concerns<br>• Increases energy and input needed for water treatment<br>• More acceptable in areas of low water security |
| **Feasibility and Technical Requirement** | • Utilizes existing infrastructure but can require engineering of new distribution channels<br>• Some private-public partnership for large projects with high CAPEX<br>• Existing OPEX used, training of locals on standards, and quality assurance required |

## TABLE A.6: RAW WATER SUPPLY OPTION - DESALINATION

| | |
|---|---|
| **Overview** | |
| | Desalination is another possible response to water scarcity and can be implemented on various scales, ranging from large-scale plants to small simplified devices employing natural evaporative processes. Desalination may be considered where:<br>• There is a sufficient and convenient source of water whose salinity renders it non-potable;<br>• Finance for large capital projects with higher operating costs is available; and<br>• Alternative sources of potable water are either more expensive to develop or less reliable.<br>The operating costs of desalination are largely determined by energy costs. The economic feasibility of desalination is therefore highly dependent on the local availability and cost of energy (IRENA, 2012). Options for coupling desalination with renewable energy technologies provide the opportunity for a sustainable water supply, reduce greenhouse gas emissions and provide energy security to the water sector. |
| **Advantages** | • Offers potentially unlimited resources of water (brackish or seawater for treatment)<br>• Does not compete with existing water usage<br>• Provides potable water in poorly resourced environments (e.g., small islands)<br>• Can be powered by renewable energy to reduce OPEX and greenhouse gas emissions |
| **Disadvantages** | • High CAPEX<br>• Requires significant energy supply, thus often requires high OPEX<br>• Increased water price to recover CAPEX and OPEX<br>• Requires specific operation and maintenance skills and parts (including replacement membranes and chemicals)<br>• Systems are often exposed to coastal hazards<br>• Environmental impacts including greenhouse gas emissions and brine wastewater by-products |
| **Indicative Costs** | • Cost for design and construction of plant<br>• Portable Reverse Osmosis desalination units purchased from manufacturers<br>• Production costs |
| **Timing for Implementation** | • Large-scale plants can take up to a decade to complete (McGrath 2010)<br>• Small systems usually take at least 24 months for construction and commissioning<br>• Simplified portable units are typically manufactured off-site for immediate use |
| **Governance** | • Public-Private Partnership arrangements required to meet CAPEX and OPEX<br>• Comprehensive public consultation required for large-scale systems<br>• Renewable energy technologies require government and industry support and policy targets to ensure technologies are made affordable and accessible |
| **Acceptability** | • Negative perception of desalination is common<br>• Can be considered as maladaptation as it requires significant energy supply, generating increased greenhouse gas emissions<br>• Public opposition to increased water price for the consumer<br>• Disposal of brine wastewater can result in unavoidable environmental impacts |
| **Feasibility and Technical Requirement** | • Requires extensive engineering and construction management expertise (most likely provided through external procurement and international companies)<br>• Requires specific skills for operation and maintenance tasks (requires extensive training of local personnel) |

## TABLE A.7: WATER QUALITY PROTECTION - SOURCE PROTECTION

| Overview | |
|---|---|
| | Quality of a water source can be impacted by natural and human influences alike. A reduction in quality means it may not be used for drinking or agricultural purposes, thus potentially reducing the total quantity of useable water in an area. Measures to improve water quality would help communities in using all available water resources effectively. Ensuring protection of water sources from contamination reduces issues of scarcity and increases water security.<br>General measures for source protection:<br>• Storage of water to help reduce contaminants;<br>• Maintenance of pipes; and<br>• Testing and monitoring of catchment area quality.<br>Surface water is most prone to contamination from runoff leading to problems such as eutrophication. Increased turbidity from heavy rainfall events can also reduce quality. Groundwater can become saline if extraction is not managed sustainably. Measures to ensure quality include salinity and flow barriers, regulation of agricultural input and animal access to water source, effective treatment facilities, and suitable storage facilities (jars, tanks etc.). |
| **Advantages** | • Maintains all accessible water for effective use<br>• Additional health and environmental benefits by reduction of pollutants |
| **Disadvantages** | • Does not provide increased water access<br>• Testing and monitoring schemes can be timely and non-cost effective – high levels of operation and maintenance |
| **Indicative Costs** | • Water storage tanks or storage reservoirs |
| **Timing for Implementation** | • 2 - 12 months |
| **Governance** | • Consultation required with affected landholders and community groups, industry groups and relevant government agencies |
| **Acceptability** | • Highly acceptable by utilities and community |
| **Feasibility and Technical Requirement** | • Utilizes existing infrastructure but can require engineering of storage tanks, treatment facilities<br>• Maintenance of pipes, and testing and monitoring of catchment area quality requires labor and knowledge |

## RAINWATER HARVESTING

### TABLE A.8: RAINWATER HARVESTING - REVIEW AND UPGRADE OF CURRENT HOUSEHOLD RAINWATER SYSTEMS

| Overview | |
|---|---|
| | Rainwater harvesting primarily consists of the collection, storage and subsequent use of captured rainwater as either the principal or as a supplementary source of water.<br>Rainwater harvesting can be efficient as a complementary and viable alternative to large-scale water withdrawals, reduce negative impacts on ecosystems services and serve as an important adaptation strategy for people living with high rainfall variability or a lack of suitable surface or groundwater resources.<br>Systems can vary from small and basic, such as the attachment of a water collection pipe to a rainwater downpipe, to large and complex, such as those that collect water from many hectares and serve large numbers of people.<br>Review and upgrade of existing rainwater harvesting infrastructure may include review of components such as:<br>• Catchment surface from which runoff is collected, e.g., a roof surface;<br>• System for transporting water from the catchment surface to a storage reservoir;<br>• Reservoir where water is stored until needed; and<br>• Device for extracting water from the reservoir. |
| **Advantages** | • Technology is flexible and adaptable to a very wide variety of conditions<br>• Improved systems will reduce pressure on water resources, reduce local flood risk<br>• OPEX typically minimal<br>• Highly decentralized – improved self-sufficiency |
| **Disadvantages** | • Upgrade requirements will vary between households, increasing project complexity<br>• Will only have an effect with widespread uptake<br>• Introduction of technology, such as pumps, may complicate operation and maintenance requirements<br>• Moderate CAPEX<br>• Lack of capacity or willingness for residents to manage their own decentralized form of water supply<br>• Depleted access to water downstream |
| **Indicative Costs** | • Significant time costs associated with review of individual households<br>• For a given tank the purchase and installation costs are related to the storage capacity – balance between cost and performance requirements<br>• Cost of new tank, additional minor costs of collection and distribution infrastructure (downpipes etc.) |
| **Timing for Implementation** | • 2 - 3 months for review of existing infrastructure<br>• Upwards of 12 months for upgrade and installation of new infrastructure<br>• Time-frames highly dependent on specific community requirements |
| **Governance** | • Rainwater harvesting not included in water policies in many countries<br>• Intervention with primarily local benefits - potential for conflicts with downstream users<br>• Stakeholder consultation and public participation are key |
| **Acceptability** | • Little public opposition against and considerable support for the use of harvested water<br>• Uptake likely to be dependent on existing culture of water conservation<br>• Aversion to new technology or inability to foresee return on upfront costs |
| **Feasibility and Technical Requirement** | • Rainwater harvesting technologies are simple to install and operate. Local people can be easily trained to implement such technologies, and construction materials are usually readily available |

## TABLE A.9: RAINWATER HARVESTING - INCREASED RAINWATER HARVESTING CAPACITY THROUGH INSTALLATION OF ADDITIONAL HOUSEHOLD RAINWATER TANKS OR COLLECTION JARS (FULLY FUNDED AND CONSTRUCTED)

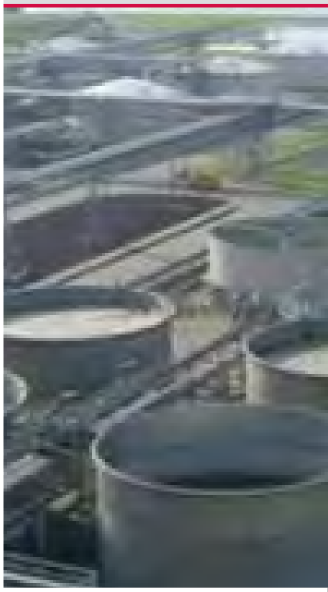
| Overview | |
|---|---|
|  | A storage device is required to collect and hold catchment runoff because rainfall events occur more erratically than system demand. Water storage capacity is required in order to balance out the difference between supply and demand. Tanks for domestic systems generally have storage volumes in the 1-10$m^3$ range. Tanks for commercial systems are available in a wider range of sizes and can be tens or hundreds of cubic meters in size. Vessels can also be linked together to provide additional volume meaning that there is no theoretical upper limit on the amount of storage space that can be provided, site constraints notwithstanding. Installing tanks underground has a number of advantages: it helps to prevent algal growth by shielding the tank from daylight (Konig, 2001), protects the tank from extreme weather conditions at the surface such as freezing spells and helps to regulate the water temperature in the tank, keeping it cool and limiting bacterial growth.<br>Given the intermittent nature of rainfall, it is rare that a rainwater harvesting system can be designed such that a constant supply of harvested water can be guaranteed. In times of shortfall it is advisable to have a top-up arrangement that can supply enough water mains to meet short-term demand. Top-up can be provided in a number of locations. In an indirect system it most commonly occurs in the header tank, although it can also be in the storage tank. Solenoid valves are typically used to start and stop the mains, top-up function. |
| **Advantages** | • Increased potential for rainwater harvesting<br>• Can release time from water fetching activities<br>• Reduce pressure on water resources (potentially offsetting need to develop further resources) |
| **Disadvantages** | • Depleted access to water downstream<br>• Increased CAPEX and OPEX with larger or greater number of storage tanks<br>• Fluctuating variability of rainfall, no guarantee of supply (particularly in tropical regions where rainfall is seasonal)<br>• Stagnant water storage has a great capacity for bacterial growth if not managed correctly |
| **Indicative Costs** | • Tank and storage vessels<br>• 16,000 liters cistern per household |
| **Timing for Implementation** | • 2-12 months depending on number and type of vessels required |
| **Governance** | • Small-scale community projects require community-government-NGO coordination<br>• Large projects public-private partnerships for initial CAPEX<br>• Public consultation required for size and suitability of vessel type, plus knowledge and skills sharing |
| **Acceptability** | • Supported by communities as a safe source of water<br>• Moderate-low CAPEX makes it appealing to government and funding bodies |
| **Feasibility and Technical Requirement** | • Construction and operation and maintenance skills training for local labor<br>• Material imports depending on storage type<br>• Larger connected storage facilities require some design and engineering input |

## TABLE A.10: RAINWATER HARVESTING - INCREASED RAINWATER HARVESTING CAPACITY THROUGH INSTALLATION OF COLLECTIVE RAINWATER HARVESTING SYSTEM

| Overview | |
|---|---|
|  | A collective rainwater harvesting system consists of a series of interlinked rooftop catchments to flow into a centralized tank or cistern. This can include a series of private, communal and large community or village tanks. The benefit of collective systems is that it allows all members of society to access water regardless of individual capacity for collection or storage. The system depicted to the left, demonstrates individual and communal catchments, where in this instance all viable catchment rooftops are rented by a utility. 50 percent of rooftop runoff is stored for personal use, and the rest goes into collective storage (SI-USA, 2012). In past projects training of locals includes the testing of water quality and ensuring knowledge sharing between community members of correct care for their cistern.<br>In rural settings these systems increase water security and decrease dependence on groundwater or reservoir extraction. In cities, collective systems reduce stress on stormwater infrastructure and runoff loading on sewage pipes. These systems also offer an alternative if pollution of local sources occurs, and can help recharge aquifers impacted by salinity. They also function as an adaptation against rainfall variability where storage in larger systems during the wet season can be used by the whole community during droughts. (UNDP, 2012). |
| **Advantages** | • Decreased per capita investment<br>• Increased community access to water during scarcity<br>• Reduce stress on river and groundwater source |
| **Disadvantages** | • High infrastructure disturbance to local areas through placement of tanks and pipes<br>• Potential for health risks through poor management of stagnant water |
| **Indicative Costs** | • Cistern<br>• Reconnection of gutter downpipes<br>• Rebate and Subsidies schemes |
| **Timing for Implementation** | • 4-12 months |
| **Governance** | • Public-Private-Community coordination and consultation<br>• International support for CAPEX, OPEX and some materials |
| **Acceptability** | • Rainwater harvesting is viewed as traditional and equitable form of water distribution<br>• Low level of input and management required after initial construction |
| **Feasibility and Technical Requirement** | • Design, architectural and construction support<br>• Train locals with construction techniques<br>• Basic operation and maintenance required for sustainable system use |

# WATER QUALITY PROTECTION AND WATER TREATMENT

## TABLE A.11: TREATMENT MEASURES - ADJUST TREATMENT TECHNOLOGY

| Overview | |
|---|---|
|  | As availability of water decreases there is a need to innovate and use non-traditional water sources (sea or brackish water) and create varying standards of water quality for specific uses. Additionally, improving efficiency of existing systems can reduce energy consumption and limit emissions. Adjustments need to also occur for regions where an increase temperature and drought can lead to soil shrinkage and pressure on pipes.<br>Recent developments in water and wastewater treatment technology provide opportunities to improve the resilience of treatment facilities in addition to quality and efficiency improvements. These include:<br>• Organics removal;<br>• Bacterial treatment and disinfection;<br>• Reduction of membrane fouling; and<br>• Improvements in salt removal.<br>For example, by using variable speed drives on the system, energy efficiency can be attained while the system can cope with more fluctuation in the demand. The technological advancements in membrane technology have made the desalination and water reuse more affordable to water supply and sanitation services providers. Not only can energy be saved, but there is the potential to turn all wastewater treatment plants into renewable energy producers (Bloom and XPV Capital Corporation, 2010).The proper balance of treatment performance and demand requirement need to be carefully understood and planned. The pursuit of the latest or most advanced technology without addressing the supply and demand requirements can become counter-productive and result in excessive capital investment. |
| **Advantages** | • Improved efficiency in water and energy use<br>• Shift towards non-traditional water sources for specific sectors<br>• OPEX reduced over time |
| **Disadvantages** | • Does not address supply issues or pollution and contamination points<br>• High CAPEX and OPEX for creation of new treatment systems. |
| **Indicative Costs** | • Rebuild and upgrade of existing plant<br>• New membrane bioreactor system |
| **Timing for Implementation** | • 12 months for technology installation<br>• 2-4 years for new plant rebuild |
| **Governance** | • Utilities and respective engineers for the improvement of existing structures. No community involvement necessary<br>• External technological guidance and input, where improvements are large or costly and private-public partnership may be required for CAPEX |
| **Acceptability** | • Highly acceptable where cost of supply does not increase and no additional impact on the local community is made<br>• Favorable by utilities were operational costs can be reduced through efficiency |
| **Feasibility and Technical Requirement** | • Relevant local utility operators needed for consultation<br>• Operation and maintenance training of locals needed for new technology types |

## TABLE A.12: WATER QUALITY PROTECTION - IMPROVE WASTEWATER COLLECTION SYSTEM AND TREATMENT CAPACITY

| Overview | |
|---|---|
| | Typically, urban sanitation consists of the collection of wastewater in sewers, its treatment in a wastewater treatment plant, and reuse or disposal in rivers, lakes or the sea. Wastewater systems can operate at a municipal or community level, and can be on-site or off-site.<br>Wastewater collection and treatment is designed to address effluent water quality issues and water scarcity issues. Wastewater treatment technology can provide communities and facilities with resilience and efficiency improvements.<br>Water shortages are a key issue driving innovations in treatment technology. The cost of wastewater treatment increases with greater energy costs and demands. Alternative wastewater collection systems, such as condominial sewerage, may be preferable to conventional systems due to the reduced cost. Currently, advanced treatment research projects are aimed at developing technologies in three critical areas:<br>• Developing and improving performance of treatment membranes to maintain water quality;<br>• Efficient recovery of resources from water and wastewater streams; and<br>• Water quality assurance for consumers of water and treated wastewater.<br>There is evidence to show that a variety of wastewater treatment options are feasible for use in the developing world and that many low-technology options can be mixed and matched for very high efficiencies, such as natural treatment technologies (Rose, 1999). |
| **Advantages** | • Working towards solution to water scarcity problems<br>• Cost effective for future energy demands |
| **Disadvantages** | • High investment cost of conventional systems prohibitive<br>• Plant requires energy to pump the waste around<br>• Mental opposition to drinking treated wastewater<br>• Potential for wastewater recycling loops and subsequent contamination |
| **Indicative Costs** | • Variables include: scale of system (volume being treated), standard of output, consistency of inputs<br>• Upfront costs |
| **Timing for Implementation** | • Large-scale (municipal) system: 6 months to a few years<br>• Small-scale (community) system: 2 months to a year |
| **Governance** | • Large-scale (municipal) system: requires significant public investment<br>• Small-scale (community) system: requires community buy in and ongoing investment in maintenance |
| **Acceptability** | • Highly acceptable at community and government scales |
| **Feasibility and Technical Requirement** | • Highly dependent on scale of treatment |

## TABLE A.13: WATER QUALITY PROTECTION - SALINITY PREVENTION

| Overview | |
|---|---|
| | A number of different measures have been used to control seawater intrusion and to protect the groundwater resources. The main principle of protection is to increase the volume of fresh groundwater and reduce the volume of saltwater. Various means of preventing saltwater from contaminating groundwater sources include (Todd. 1974): (1) Reduction of the abstraction rates; (2) Relocation of abstraction wells; (3) Subsurface barriers; (4) Natural recharge; (5) Artificial recharge; (6) Abstraction of saline water; and (7) Combination of injection and abstraction systems.<br><br>Extensive research has been carried out to investigate saltwater intrusion in coastal aquifers. However, only a few models have been developed to study the control of saltwater intrusion. These models use one or more of measures identified above to study the control of saltwater intrusion. The reduction of abstraction rates aims to reduce the pumping rates and use other water resources. The relocation of abstraction wells aims to move the wells further inland. Subsurface barriers aim to prevent the inflow of seawater into the basin (Harne et al. 2006). Natural recharge aims to replenish aquifers with additional surface water.<br><br>Artificial recharge aims to increase the groundwater levels, using surface spread for unconfined aquifers and recharge wells for confined aquifers. The sources of water for injection may be surface water, groundwater, treated wastewater, or desalinated water. The abstraction of saline water aims to reduce the volume of saltwater by extracting brackish water from the aquifer (Sherif and Hamza 2001).The combination of injection of freshwater and extraction of saline water can reduce the volume of saltwater and increase the volume of freshwater. |
| **Advantages** | • Restores quality to existing potable water supply for short term use<br>• Uses existing infrastructure for storage and distribution |
| **Disadvantages** | • Temporary solutions to an increasing problem<br>• Does not address long-term issues from continual with increased salt intrusion<br>• Moderate CAPEX and OPEX required<br>• Movement of potable water from accessible points (surface) to storage facilities requires additional extraction for future use<br>• Long term planning required to reduce the need for future repair and relocation |
| **Indicative Costs** | • Subsurface barrier several US$million<br>• OPEX ongoing for lifespan of barrier<br>• Artificial recharge methods US$1 – 25 per 1000m$^3$/year (IWMI, 2012) |
| **Timing for Implementation** | • 2 - 12 months |
| **Governance** | • Local community consultation required for subsurface barrier placement |
| **Acceptability** | • Contested acceptability over balance of inputs to outputs. The cost and energy involved in restoring a unit of water can outweigh the short term benefits by adding to the greehouse gases (GHG) responsible for sea level rise |
| **Feasibility and Technical Requirement** | • Subsurface systems are commonly used for wastewater containment, similar technology applicable to sea level rise making engineering skills accessible<br>• Operation and maintenance requirements are minimal for recharge sites; monitoring skills easily transferable to locals for subsurface barrier<br>• Labor and materials costs of rebuilding, relocating or repairing infrastructure using damage resistant techniques |

## POLICY AND PLANNING

### TABLE A.14: RAINWATER HARVESTING - INCREASED RAINWATER HARVESTING CAPACITY THROUGH FINANCIAL INCENTIVES ONLY (INCLUDING PROVISION OF MATERIALS ONLY)

| Overview | |
|---|---|
|  | A range of financial incentives exists for improving household rainwater harvesting capacity. Financial incentives include: rebates, mandates, tax credits, tax breaks, grants, funding, and progressive water tariffs. Urban and rural environments employ different approaches to rainwater harvesting and require different levels of governance. In rural settings rainwater harvesting includes a simple structure for rooftop rainwater harvesting and storage facilities required for human consumption.<br>In the cities it is a combination of access to water, varying quality requirements for uses, and minimization of runoff. Providing financial incentives to increase rainwater harvesting can involve and benefit all levels of society, including users and government. The employment of local community and NGO groups are an efficient way to distribute materials and funding.<br>Financial incentives can be raised from diverse sources and account for income disparities. For example, money raised from increased groundwater extraction fees can be used to subsidize rainwater harvesting projects in rural areas. Furthermore, differential pricing schemes for water use by industry versus domestic use may support equity. Any water pricing needs to consider the overall social, economic, and financial objectives for integrated water resource development (UNWAC, 2011). |
| **Advantages** | • Reduces pressure on municipal water systems<br>• Reduces cost of water consumption for households |
| **Disadvantages** | • Larger CAPEX for adequate supply<br>• Highly responsive to government pressures and economic situations to access funding<br>• Multi-level coordination |
| **Indicative Costs** | • 16,000L cistern<br>• Reconnection of gutter downpipes<br>• Rebate and subsidies schemes |
| **Timing for Implementation** | • 1-2 years |
| **Governance** | • Public-Private-NGO funding for required CAPEX<br>• State water utility also disseminates information on rainwater harvesting<br>• Public consultation over appropriate scheme and infrastructure |
| **Acceptability** | • Community consent where cisterns and tanks don't disturb land use<br>• Moderate acceptability from government regarding costs, taxes and public expenditure |
| **Feasibility and Technical Requirement** | • State water utility provides technical assistance on adopting rainwater harvesting practices<br>• OPEX and operation and maintenance for construction of the cisterns, local labor<br>• Training of specialists on efficient and affordable devices to conserve water, facilities to use rainwater and devices to enhance the underground seepage of rainwater |

## TABLE A.15: NON-REVENUE WATER MANAGEMENT AND LEAKAGE CONTROL

| Overview | |
|---|---|
| | Non-Revenue Water (NRW) is water that does not reach the customer from the distribution lines. This is often due to pipe leakage, theft or metering inaccuracies. NRW affects the financial viability of water utilities. The World Bank estimates the total cost to water utilities worldwide caused by NRW each year to be USD14 billion, with over 45 million $m^3$ of water lost daily, the equivalent of needs for 200 million people (Kingdom et al., 2006). Suggested solutions include:<br>• Increase government strength and facility frameworks around water utilities;<br>• Develop a NRW strategy to encompass time and resources required for awareness, location and repair (Farley et al., 2008);<br>• Repair leaking pipes and damaged systems;<br>• Invest in technology to develop advanced systems;<br>• Increase and enforce monitoring of consumption data;<br>• Create specialist management and technical expertise in NRW management; and<br>• Utility-to-utility partnerships, known as "twinning" arrangements, to enhance the capacity of water service providers (Farley et al., 2008).<br>A potential viable solution encompassing a range of those above is "performance-based service contracting". This is viewed as a more efficient model, especially where water utilities are still publicly managed. This method employs a private company for its technical expertise, and incentives are given to ensure performance accountability including payment based on actual results achieved (Kingdom et al., 2006). Public based initiatives can be set up following guidelines from the International Water Association (IWA) to establish correct water balances (Farley et al, 2008). |
| **Advantages** | • Reduces commercial losses and generates more revenue for water sector<br>• Costs of improved service delivery through investments in NRW reduction are much lower than investments in capital projects to develop additional supply<br>• Improves the efficiency and sustainability of current water resources |
| **Disadvantages** | • Difficult to eliminate NRW entirely<br>• Lack of understanding of the magnitude of the problem and access to network information<br>• Typically impeded by low financial and human resource capacity<br>• Requires significant CAPEX to repair or replace infrastructure and OPEX costs associated with ongoing monitoring and maintenance<br>• Service interruptions during maintenance and repair<br>• Requires long term commitment for utility managers |
| **Indicative Costs** | • Varies depending on the method used (e.g., technology, performance based contracting, etc.) |
| **Timing for Implementation** | • 5-10 years for completion of goal of halving NRW |
| **Governance** | • National and local government and the water utility sector<br>• Relevant funding body through public-private partnerships |
| **Acceptability** | • Supported by both consumers and utilities for improved efficiency in service<br>• Government concerns regarding cost, and size of infrastructure replacement |
| **Feasibility and Technical Requirement** | • Requires advanced plumbing work<br>• Moderate engineering and construction management for the rebuilding of highly damaged systems.<br>• Ongoing OPEX and operation and maintenance for monitoring of new system including a trained management board |

## WATER DEMAND MANAGEMENT MEASURES

Water demand management has long been acknowledged as a critical tool to cope with the pressures of growing populations and their demand for natural resources. Intensifying water scarcity, problems with deteriorating water quality, and the effects of more severe and frequent extreme climatic events (storms, floods and droughts) will almost certainly increase the need for demand management measures.

The proper balance of demand management and technical designs need to be carefully considered as poorly planned conservation efforts can be counter-productive to a utility's financial and operational stability. Running existing infrastructure, primarily pumping equipment and networks, below designed capacity can lead to operational difficulties and prove financially risky. For example, it may be costly and difficult to maintain pressure within oversized networks that are designed for specific levels of consumption. Gravity fed sewerage can also be affected as minimum flow levels may not be met and result in the clogging of pipes. Wastewater treatment plants may also face operational challenges due to low wastewater flow and contaminant levels in the wastewater that do not correspond to a system's existing technology.

Demand-side management, including the reduction of leakage in the distribution networks and water conservation measures are more often applied to address water scarcity in developed country situations, and cities. Distributional losses in emerging countries are typically high and can exceed 25 percent of total water use in older systems.

### TABLE A.16: DEMAND MANAGEMENT - WATER METERING AND TARIFF

| Overview | |
|---|---|
| | Water metering is the most efficient tool for reducing domestic water consumption. Water metering facilitates the principle of the consumer paying for their consumption. Coupled with an appropriate tariff policy, this can result in reducing water demand or wastage and protect poorer elements of society. Evidence shows that utilities that switch from a fixed fee (flat rate) billing system to universal metering experience a reduction of water use among customers in the order of 30 percent, with an upper limit being as high as 50 percent (AWWA, 2008).<br>Tariff is a key instrument in demand management, yet it is widely known that tariff adjustments can be politically challenging and difficult to implement. As a result, urban water utilities in developing countries often are unable to cover the recurrent costs of operation and maintenance, leaving little or no funds to recover capital costs, or invest in modernization or system expansion (World Water Assessment Programme. 2009). |
| **Advantages** | • Accurate and nationally consistent<br>• Assistance for users to identify areas where efficiency can be improved and minimize water lost through delivery systems<br>• General trend of decreasing domestic water use<br>• Tariff system can be used to encourage households to use less water |
| **Disadvantages** | • Problems with meter readings arise with intermittent supply<br>• Fitting an apartment block with separate meters in each apartment can be very costly with complex plumbing work |
| **Indicative Costs** | • Install and purchase meters<br>• Recurrent fees to read meters and issue bills based on consumption |
| **Timing for Implementation** | • Individual residence 1 week<br>• Large residential area 1 year |
| **Governance** | • Investment from water supply department<br>• Public consultation over placement of meters on residential properties |
| **Acceptability** | • Negative-moderate acceptability due to the demand for the property owners to purchase and install meters<br>• Concerns over costing change |
| **Feasibility and Technical Requirement** | • Utilizes existing pipes with the addition of a small meter<br>• Requires plumbing expertise to install |

## POLICY AND WATER MANAGEMENT STRATEGIES

### TABLE A.17: DEVELOPMENT OF A CLIMATE INFORMED WATER POLICY AND MANAGEMENT FRAMEWORK

| Overview | |
|---|---|
| | Adaptation to climate change in the water sector needs to be incorporated into overall policy frameworks. A recent OECD analysis of policy frameworks for water has shown that what should be done, when and by whom depends on the rate of climate change, but also on the existing policy frameworks in each country (Levina and Adams, 2006).These policy frameworks generally contain the following elements:<br>• Legal Framework: a system of legal frameworks that stipulate rights and responsibilities (e.g., water rights and abstraction permits);<br>• Institutional Strengthening: build operation and management capability for related institutions of national, regional and local levels;<br>• Policies: Produce policies that guide national, regional, state, local laws;<br>• Clarification and Division of Roles: clearly define role for players (Governments, Ministries, departments, regulators and other authorities);<br>• Development of Infrastructure: Build physical water infrastructure such as dams, levees reservoirs and sewerage systems;<br>• Plans of Actions: Develop a set of water management plans with the flexibility to anticipate and respond to climate change; and<br>• Effective Uses and Sharing of Information: Establish a good practice and system for sharing current and projected climate information.<br>Interactions at different scales of governance are recognized as critical. Multi-level governance operates vertically across multiple levels of government (commune, provincial to national) and horizontally across government departments as well as non-government actors. Successful adaptation requires interactions between different levels of government since adaptation at one level can strengthen or weaken adaptive capacity and action at other levels; local institutions can block or support higher-level organizations.<br>Furthermore, it should be noted that river catchments are probably the best spatial scale to be considered for an effective implementation of raw water resources management plans. This can prove difficult for transnational rivers. |
| **Advantages** | • Low CAPEX<br>• Many existing templates to model policy and framework upon<br>• Structure for future projects and long term planning |
| **Disadvantages** | • Requires broad government coordination across sectors and levels<br>• Technical knowledge and expertise required<br>• Does not address immediate water concerns |
| **Indicative Costs** | • Varies depending on policy applied |
| **Timing for Implementation** | • 12 - 18 months |
| **Governance** | • Commune, provincial and national government coordination and input<br>• Dialogue with international governing bodies to ensure criteria and standards are addressed |
| **Acceptability** | • High acceptability where government communication is good<br>• Does not require tangible outcomes or impacts upon communities |
| **Feasibility and Technical Requirement** | • Access to the requisite knowledge, expertise and technical skills<br>• Guidance from experienced climate policy writers<br>• Training of local government staff for policy and framework requirements |

## TABLE A.18: DEVELOPMENT OF WSUD GUIDELINES

| Overview | |
|---|---|
| | WSUD guidelines typically address issues around water supply and demand management with a strong focus on green infrastructure, while also considering the risks associated with non-potable water sources. The guidelines would include sections to guide practitioners on green infrastructure benefits, alternative water sources, risk management, site analysis and water balance assessment and end use and treatment required. More detailed information would be developed for specific green infrastructure elements such as rainwater tanks, stormwater biofiltration and constructed wetlands.<br>The guidelines would not provide detailed technical information but, rather, a general description of the key WSUD fundamentals. The guidelines would be a relatively short document with a strong emphasis on graphic display of the information and easy to understand principles. The guidelines would represent the cheapest and easier to implement options from a WSUD perspective. The benefits from an improved water management perspective would be more limited than the development of WSUD strategy. |
| **Advantages** | • Enhances the current level of understanding of WSUD<br>• Provides a framework for consistent implementation and integration of WSUD in new developments<br>• Provides design guidance on WSUD details<br>• Identifies issues that should be considered when evaluating strategies to achieve WSUD<br>• Supplements (but not replaces) existing WSUD regulations and detailed design and implementation guidelines<br>• Directs readers to more detailed technical WSUD literature on specific issues and for location specific advice |
| **Disadvantages** | • WSUD guidelines would be more limited than a WSUD strategy due to their general nature<br>• Do not take site specific conditions into account, including topography, soils, landscape, services and other relevant site features and structural elements<br>• Not a stand-alone design resource |
| **Indicative Costs** | • The cost of developing WSUD guidelines would be minimal as it would not involve any specific investigations or site-specific details |
| **Timing for Implementation** | • The development of WSUD guidelines can be achieved in weeks to months |
| **Governance** | • WSUD is mandatory for certain scales and types of developments<br>• WSUD would require involvement from relevant water utilities and their engineering divisions (or external procurement)<br>• Stakeholder consultation is key |
| **Acceptability** | • High acceptability – usually WSUD does not result in significant disturbance to local communities<br>• Little public opposition against, and considerable support for, the use of WSUD<br>• Some aversion to new technology |
| **Feasibility and Technical Requirement** | • Some WSUD technologies are simple to install and operate. Local people can be easily trained and construction materials are usually readily available<br>• Primarily requires common engineering practices; however, some specific engineering inputs are required for design and construction as well as for specific materials that may not be local<br>• Existing local skills associated with current facilities can be used for operational purposes<br>• May require advanced plumbing work |

## TABLE A.19: DEVELOPMENT OF A WSUD STRATEGY AND IMPLEMENTATION OF WSUD OPTIONS

| Overview | |
|---|---|
| | A detailed site analysis and water balance assessment would be the first step of a WSUD strategy. The following site characteristics should be considered as part of a detailed site analysis:<br>• Climate (rainfall - annual average, seasonal variation);<br>• Topography (steep slopes, vicinity to natural waterways);<br>• Soils and geology (suitability for infiltration);<br>• Groundwater (depth to water table);<br>• Salinity (acid sulphate soils);<br>• Space (potential areas for water treatment and storage);<br>• Services (conflicts with existing and proposed);<br>• Environmental (significant species); and<br>• Heritage (retrofitting plumbing on heritage listed buildings).<br>Secondly, an assessment of the end use and treatment required should include at least a general water breakdown in terms of internal water use (e.g., drinking, showers, toilets and laundry), external water use (e.g., irrigation, industrial plant, cooling towers), and an assessment of the suitability of alternative water sources (rainwater, stormwater, groundwater and recycled water). Finally the strategy should determine the right balance of green infrastructure to be implemented to ensure the long term efficiency of the WSUD measures. |
| **Advantages** | • A WSUD strategy allows for the integration of all WSUD elements within the development<br>• A WSUD strategy would be site and development specific as each site has specific environmental conditions that influence implementation of WSUD, such as rainfall, topography, soils, creeks and receiving waters |
| **Disadvantages** | • WSUD upgrade requirements will vary between households and developments, increasing project complexity<br>• WSUD will only have an effect with widespread uptake |
| **Indicative Costs** | • The cost of developing a WSUD strategy and implementation of WSUD options would vary on a site by site basis |
| **Timing for Implementation** | • The development of a WSUD strategy and implementation of WSUD options can be achieved in months to years, depending on site specific details and requirements |
| **Governance** | • WSUD is mandatory for certain scales and types of developments<br>• WSUD would require involvement from relevant water utilities and their engineering divisions (or external procurement if they don't have internal capacity), participation of the general community is not required<br>• Stakeholder consultation is key |
| **Acceptability** | • High acceptability – usually WSUD does not result in significant disturbance to local communities<br>• Little public opposition against, and considerable support for, the use of WSUD<br>• Some aversion to new technology |
| **Feasibility and Technical Requirement** | • Some WSUD technologies are simple to install and operate. Local people can be easily trained to implement such technologies, and construction materials are usually readily available<br>• Primarily requires common engineering practices however, some specific engineering inputs are required for design and construction as well as relevant materials that may not be local<br>• Existing local skills can be used for operational purposes<br>• May require advanced plumbing work |

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