USAID
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A GUIDE FOR USAID PROJECT MANAGERS

SANITATION

INCORPORATING CLIMATE CHANGE ADAPTATION IN INFRASTRUCTURE PLANNING AND DESIGN

NOVEMBER 2015

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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 a wastewater treatment field technician (credit: USAID Philippines Sanitation Alliance) and the second image shows a swimming hole in Haiti (credit: DeNatale, 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

SANITATION

CONTENTS

ACRONYMS

CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
MCA	Multi-Criteria Analysis
OPEX	Operational Expenditure
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.

USAID ECO-ASIA

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 Infrastructure Planning and Design*. The 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 rebuild resilience.

As a part of the suite on tools for incorporating climate resiliency into engineering design, this particular guide concentrates on wastewater and sanitation infrastructure, with the overall objective of supporting the consideration of climate change risks and adaptation in USAID sanitation infrastructure development activities. This guide will be useful for those considering specific engineering design options to make sanitation infrastructure more resilient in a climate altered future - the focus of this guide will be on wastewater sanitation and will not address solid waste. It provides engineering and non-engineering development professionals with an overview of potential impacts on sanitation 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 sanitation infrastructure. The focus of this document is not on mitigation of greenhouse gas emissions related to sanitation infrastructure construction or operation.

A SUITE OF TOOLS

Accompanying this sanitation guide are additional primers that focus on flood management, potable water structures, roadways, bridges, 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 SANITATION 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 sanitation 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 sanitation 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 might 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 wastewater treatment plant with a design life of 30 years or more should consider climate change impacts. On the other hand, a small-scale wastewater collection pipeline that can be repaired cost effectively following an extreme climate event may not need to be fully climate resilient.

A STEPWISE APPROACH TO CLIMATE RESILIENT DESIGN

Following a climate resilience framework when developing and evaluating sanitation infrastructure design will help practitioners improve the effectiveness of these investments. *USAID's Climate Resilient Development Framework* (2014) promotes the adoption of development strategies and infrastructure activities that integrate risk considerations in order to create more climate resilient infrastructure and thereby enhance cost effectiveness of interventions. These goals can be realized by following a five-step approach to:1) establish the context; 2) conduct a vulnerability assessment; 3) conduct a risk assessment; 4) develop an adaptation strategy; and 5) implement activities in support of climate resilient infrastructure (addressed in Chapter 3).

This framework should be used by practitioners to establish what climate change impacts existing, or future, infrastructure assets may face (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, 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 conducting 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 sanitary infrastructure are provided in Table 1.

A compendium illustrating adaptation strategies available to practitioners to address potential climate change-related risks to sanitation infrastructure is also provided in an 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 WASTEWATER AND SANITATION INFRASTRUCTURE RISKS AND ADAPTATION MEASURES

Climate Drivers	Climate Impacts and Risks	Adaptation Measures
Drought, Reduced Available Water, Wildfires	• Water restrictions reduce wastewater flows leading to increased incidence of blockages and unhygienic conditions in combined sewers • Long-term declines in surface water availability could decrease the viability of waterborne sewerage and decrease the ability of surface water sources to dilute and attenuate pollutants • Pit latrines are vulnerable to Wildfires; increased temperatures may increase need for odor control	• Low flows may require alternative methods to flush out sewers • Maintain and implement vegetation management practices that aim to minimize fire risk • Replace with dry or composting latrines which provide increased odor control
Extreme Precipitation Events, Less Frequent but Higher Intensity Storms, Flooding	• Pit latrines, can contribute to environmental contamination when flooded; Latrine superstructures can be damaged or washed away • Septic tanks and latrines can be inundated or filled with silt in flooding situations • Underground tanks are susceptible to soil movements when surrounding soils are saturated • More intense flooding could increase the likelihood of sewer network overload, resulting in possible overflow to the drainage network or flooding of wastewater treatment plants and creates potential for contamination • Wastewater treatment plants (which tend to be at lower elevation points) may frequently flood generating downstream pollution	• Use waterproof materials • Design sewage system with inclusion of changing precipitation projections • Size drain and stormwater systems with consideration of climate change projections • Planning of retention and safety basins to avoid overflow to the drainage network and pollution spills downstream • Integrate flood management procedures (forecasting and early warning systems) in sewer and landfill operational planning • Elevate mechanical and electrical equipment in operations or maintenance facilities
Sea Level Rise, Storm Surge	• Septic tanks and latrines within reach of sea level rise and rising groundwater levels, underground structures are susceptible to ground movements and flotation, and pits could collapse or become inundated • Trunk sewers located near sea level may be subject to increased tidal gradient, groundwater infiltration, and overload, resulting in possible reduction in capacity and increased risk of environmental spills during high rainfall events or high tides • Trunk sewers that discharge into the sea may experience backflow	• Relocate asset to an area of lower risk • Create a barrier to protect against future sea level rise - build or raise levee, floodwall, revetment, bulkhead, riprap, create or enhance wetlands, undertake beach nourishment • Construct offshore breakwaters • Install storm surge barriers • Use green engineering measures such as mangrove and reef rehabilitation to increase shoreline protection and storm surge buffers • Review location of outfall pipes (in relation to potential backflow)


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CHAPTER I

INTRODUCTION

SANITATION INFRASTRUCTURE

Contaminated and polluted drinking water result in more deaths than those through forms of violence, including war.[2] The impact on the environment is equally devastating where an estimated 90 percent of all wastewater in developing countries is discharged untreated directly into rivers, lakes, and oceans. The impacts of this pollution are felt strongest in marine ecosystems that in turn affect fisheries, livelihoods, and the food chain. Over half of the world's population lives in urban areas with inadequate sanitation infrastructure and resources to address wastewater management in an efficient and sustainable way.

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 sanitation in developing countries. Decision-making on appropriate planning and implementation approaches for a diverse range of solutions are dependent on the local context, including existing social norms and behavior, demand for improved sanitation, and socioeconomic profile.

CLIMATE CHANGE IMPACTS ON SANITATION INFRASTRUCTURE

Climate change is likely to exacerbate existing issues and constraints concerning human waste disposal and associated infrastructure. The risks associated with climate change are broad; they include physical damage to sanitation installations and sewerage systems from extreme events and flooding, and a declining viability of waterborne sewerage as water becomes scarcer.

If these risks are not carefully considered in new sanitation activities, they could present additional challenges which keep emerging countries from meeting their Millennium Development Goals 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 business case, 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 of the investment plans and the design process, development of new infrastructure and rehabilitation of existing infrastructure should be designed to be resilient to climate risks.

[2] UNEP, "Sick Water: The Central Role of Wastewater Management in Sustainable Development," available at http://www.unep. org/pdf/SickWater_screen.pdf, 2010.

HOW TO USE THIS GUIDE

The overall objective of this guide is to support the consideration of climate change risks and adaptation in USAID sanitation 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 sanitation 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 wastewater 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 sanitation 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 sanitation 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 sanitation infrastructure.

A new lagoon system for the rehabilitation of a lime stabilization facility in Tacloban City, the Philippines.

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Sludge sampling at Ma’an Wastewater Treatment Plant in Jordan

CHAPTER 2

CLIMATE IMPACTS AND RISKS

CLIMATE IMPACTS AND RISKS TO SANITATION 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 sanitation systems, and how to manage or minimize these risks in the development or rehabilitation of sanitation 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 INDENTIFYING IMPACTS TO SANITATION INFRASTRUCTURE

Climate change is likely to impact sanitation 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 sanitation 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 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, wastewater collection systems might be physically unaffected by a drought, but if water resources are diminished, the wastewater collection network may not be utilized at its full design capacity. Rising groundwater tables from either increased precipitation infiltration or sea level rise will also have indirect effects on infrastructure with an underground component, such as piped sewage collection networks, septic tanks, and possibly even latrines.

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 oversize a stormwater conveyance system designed today in order to prepare for extreme flood events anticipated in the future. 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 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 sanitation (for systems using pumps), access which may already be strained during a drought.

POTENTIAL IMPACTS ON LARGE-SCALE SANITATION INFRASTRUCTURE

For the purposes of this guide, sanitation infrastructure systems are categorized as large- and small-scale. Detailed information on these two system types and appropriate strategies for making them more climate resilient can be found in the Annex. The map on the following page also illustrates the potential climate impacts on sanitation infrastructure. Large-scale sanitation systems are usually managed and administered by private or public wastewater utilities

that provide a fee-based sewage treatment service. They typically include:

- Sewerage and Piped Collection Networks
- Sewage Treatment Facilities
- Treated Wastewater Disposal and Reuse

SEWERAGE AND PIPED COLLECTION NETWORKS

Sewerage refers to the system of collecting wastewater from users in a system of pipes that conveys the wastewater to a treatment facility. Here, we refer to that network of collecting pipes. Potential climate change impacts and consequent risks to piped collection networks may include the following:

Increased ground movements and damages to buried assets. For soil types, such as clay-based soils, climatic changes can be damaging to buried assets. Increased frequency of alternating wet and dry or hot and cold cycles and more intense floods and droughts are likely to expand and contract soils damaging buried assets. This can be a significant risk for buried sewerage collection pipes, resulting in leaks, environmental and health impacts and repair costs.

SEWAGE TREATMENT FACILITIES

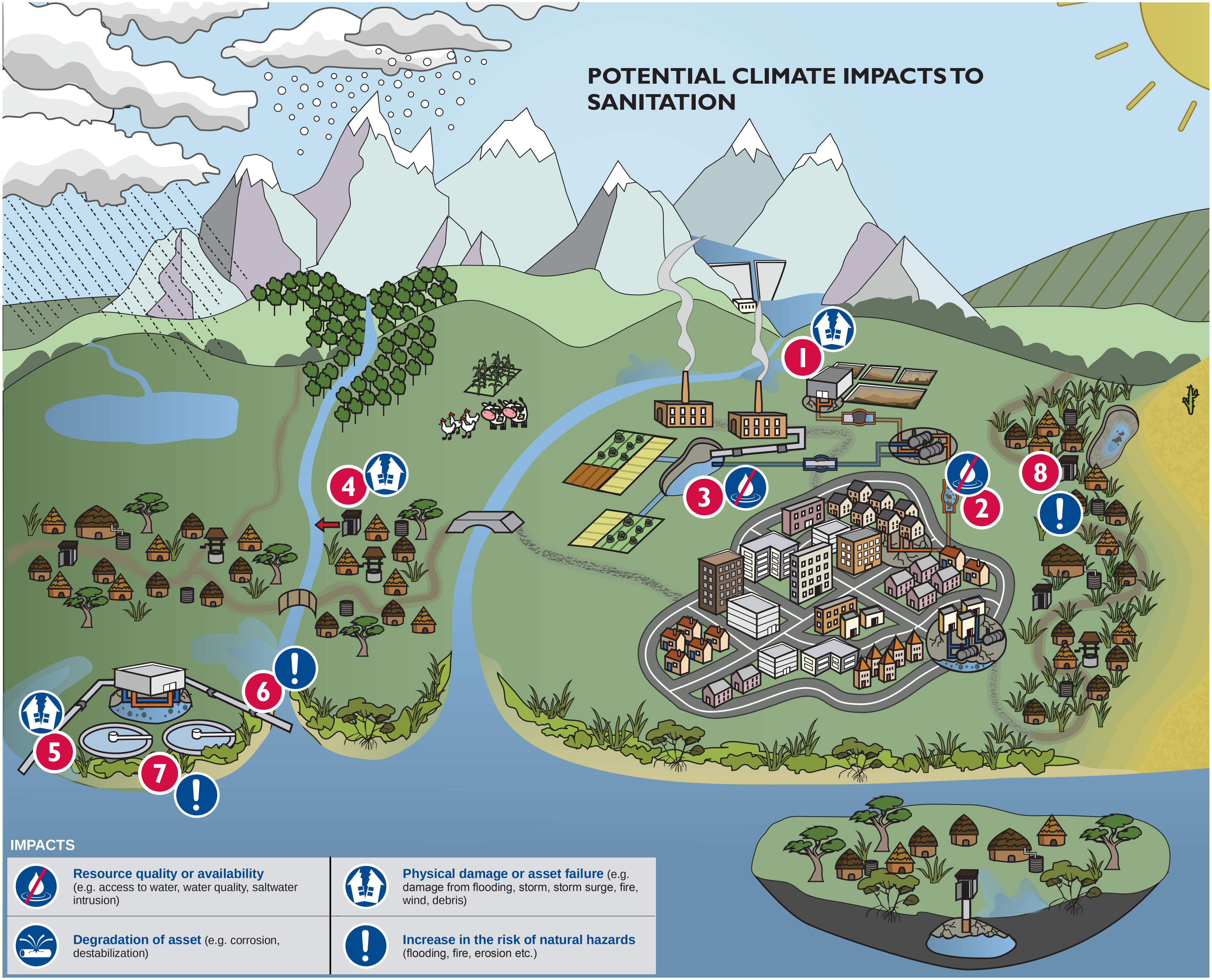
Wastewater treatment is a vital prerequisite for disposal and reuse of wastewater. The degree to which wastewater must be treated prior to disposal or reuse may be prescribed by local codes or by public health considerations. Each treatment option should be evaluated in terms of its effectiveness in removing contaminants in relation to cost. Potential climate change impacts and associated risks to wastewater treatment infrastructure include the following:

Impacts on sewage treatment plant siting. Treatment plants and associated assets are often located close 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 or storm surges.

Higher operating costs and increased stress on treatment system assets. Decreases in receiving water quality (e.g., increased sediment load and contaminants) may require additional treatment of wastewater and place additional stress on existing infrastructure; leading to higher maintenance costs and early asset renewal. Increase in temperatures may create a greater demand on waste collection and necessitate more rigorous landfill management practices for sewage treatment residuals as odors may be stronger.

Direct physical impacts on wastewater treatment infrastructure. Changes in extreme event patterns can cause direct physical damage to wastewater system infrastructure. For example, flooding, wildfire or storm events can lead to an increased risk of mechanical or electrical failure of treatment systems.

Climate change impacts on wastewater treatment and sanitation increases the risk of contamination of groundwater sources and bacterial reaction rates. It is essential to monitor any sanitation infrastructure activity throughout its life-cycle to help mitigate these risks.


POTENTIAL CLIMATE IMPACTS TO SANITATION
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IMPACTS
Resource quality or availability (e.g. access to water, water quality, saltwater intrusion)
Physical damage or asset failure (e.g. damage from flooding, storm, storm surge, fire, wind, debris)
Degradation of asset (e.g. corrosion, destabilization)
Increase in the risk of natural hazards (flooding, fire, erosion etc.)

1 Increase in extreme precipitation and extreme weather events

Climate Change Impact
Flooding and physical damage

Consequence Risk
Damage to, or complete loss of, infrastructure; overload of sewer system capacity

Vulnerable System
Wastewater collection and treatment

2 Increased variability of wet / dry spells

Climate Change Impact
Water restrictions reducing wastewater flows

Consequence Risk
Increased incidence of blockage and unhygienic conditions

Vulnerable System
Wastewater collection

3 Decrease in precipitation and increase in temperatures

Climate Change Impact
Reduced volume and quality of receiving surface water sources

Consequence Risk
Reduced ability to dilute and attenuate wastewater pollutants

Vulnerable System
Wastewater collection and treatment

4 Increase in extreme precipitation and extreme weather events

Climate Change Impact
Flooding and sedimentation

Consequence Risk
Damage to, and restricted capacity of, septic tanks and latrines

Vulnerable System
Wastewater collection

5 Sea level rise and storm surge

Climate Change Impact
Flooding and physical damage

Consequence Risk
Environmental contamination

Vulnerable System
Wastewater treatment

6 Increase extreme rainfall, sea level rise and storm surge

Climate Change Impact
Inundation or backflow of outfalls

Consequence Risk
Sewage spills, resulting from back-flow of collection system, causing environmental and public health risks

Vulnerable System
Wastewater collection

7 Sea level rise and storm surge

Climate Change Impact
Increased exposure to salt water and sea spray

Consequence Risk
Degradation of pipes and intake structures; contamination of wastewater treatment systems

Vulnerable System
Wastewater treatment

8 Decrease in precipitation and increase in temperatures

Climate Change Impact
Increased frequency and intensity of wildfires

Consequence Risk
Damage to, or complete loss of, infrastructure

Vulnerable System
Wastewater treatment

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

Reduction in water availability for large-scale sanitation systems. Most wastewater treatment processes require a reliable supply of water. However, direct changes in precipitation patterns and indirect changes in land use or non-climatic stressors within the catchment can negatively impact water resource availability, and these must be accounted for in designing climate resilient systems. Changes in the seasonality of precipitation patterns that could affect available water supplies for water treatment processes 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.

TREATED WASTEWATER DISPOSAL AND REUSE

Treated wastewater can be discharged into existing water bodies, such as local rivers or oceans. Appropriately treated wastewater can also be used to supplement freshwater use for irrigation. Potential climate change impacts and consequent risks to treated wastewater disposal and reuse include higher demand for treated wastewater as fresh water becomes more scarce. While sometimes carrying stigma, treated wastewater is already used in many water scarce locations for irrigation and other non-food uses.

POTENTIAL IMPACTS ON SMALL-SCALE SANITATION INFRASTRUCTURE

Small-scale sanitation is usually managed locally (rather than by wastewater utilities) and often includes:

- Septage Management and Treatment Facilities
- Septic Tanks
- Improved Pit Latrines
- Composting or Dry Latrines

SEPTAGE MANAGEMENT AND TREATMENT FACILITIES

The sludge that accumulates in latrine and septic tanks, that must be periodically emptied and treated, is called septage. Some urban areas have landfills or wastewater treatment plants that accept septage (local laws vary widely, with some accepting only septage hauled by vacuum truck), where other areas will depend on local haulers to land apply septage in uninhabited areas. There is the potential threat to health and the environment from toxic substances related to the generation and management of solid waste. Therefore, it is important to avoid and reduce possible groundwater contamination in order to prevent environmental degradation and spread of diseases. Septage can also be landfilled, composted, land applied, or further treated in a larger off-site treatment facility, depending on the design and the availability of local infrastructure.

Septage management approaches should be determined when installing septic tanks or latrines, and these will be susceptible to flooding and increases in variability of extreme weather events if land application or further composting is intended. Care must also be taken to ensure that proposed septage management approaches will not endanger the environment.

The potential for flooding poses the greatest risk to landfilled, lagoon, and other septage and waste treatment facilities. Site selection for waste management facilities therefore requires careful consideration when siting in floodplains, or coastal and low-lying areas. Extreme weather events, such as heavy precipitation, sea level rise and storm surge can degrade landfills and damage waste or septage containment structures. Saltwater intrusion in particular can erode or deteriorate the impermeable lining of sanitary landfilled facilities. Improper water catchment systems and damaged structures may allow debris and leachate to escape and filter into the surrounding area, contaminating local resources and groundwater. Water infiltration can also lead to overflow of the lagoon or landfilled pits, causing waste to spread or wash away.

SEPTIC TANKS

Septic systems are typically comprised of a piped connection to a household or facility-level wastewater collection system, and provide in-situ primary treatment of wastewater by allowing the solids to settle as sludge in the septic tank, and the liquid to distribute underground through a soak-away system.

Septic systems will be most appropriate in applications where sufficient land is available and soils are suitable for on-site treatment. Septic systems will be vulnerable to rising groundwater tables, but will be less vulnerable to long-term changes in precipitation or sea level rise. Short-term extreme weather and flooding presents risks for soil saturation, underground tank flotation, decreased effectiveness of soak-away systems and siltation and flooding of underground tanks.

IMPROVED PIT LATRINES

Improved pit latrines are at risk of inundation in extreme weather, and their superstructures can be damaged or destroyed in flooding, wildfire or damaging storms. A raised pit may be more suitable for conditions where high or rising water tables affect the risk of environmental contamination.

COMPOSTING OR DRY LATRINES

Composting or dry latrines have urine separation and do not allow for poured or plumbed flushing. Once full, underground pits can be filled in, composted and recovered, or septage can be removed by buckets and composted off-site. These facilities share similar risks to pit latrines.

CLIMATE CHANGE IMPACTS AND RISKS

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

Table 2 summarizes potential climate impacts posed by a range of climate stressors and their effects, and the consequent risks to sanitation 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.

A lime pit being constructed in Tacloban in the Philippines

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TABLE 2: SANITATION INFRASTRUCTURE

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


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CHAPTER 3

A CLIMATE RESILIENT INFRASTRUCTURE METHODOLOGY

ENABLING CLIMATE RESILIENT PLANNING AND DESIGN OF SANITATION INFRASTRUCTURE

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

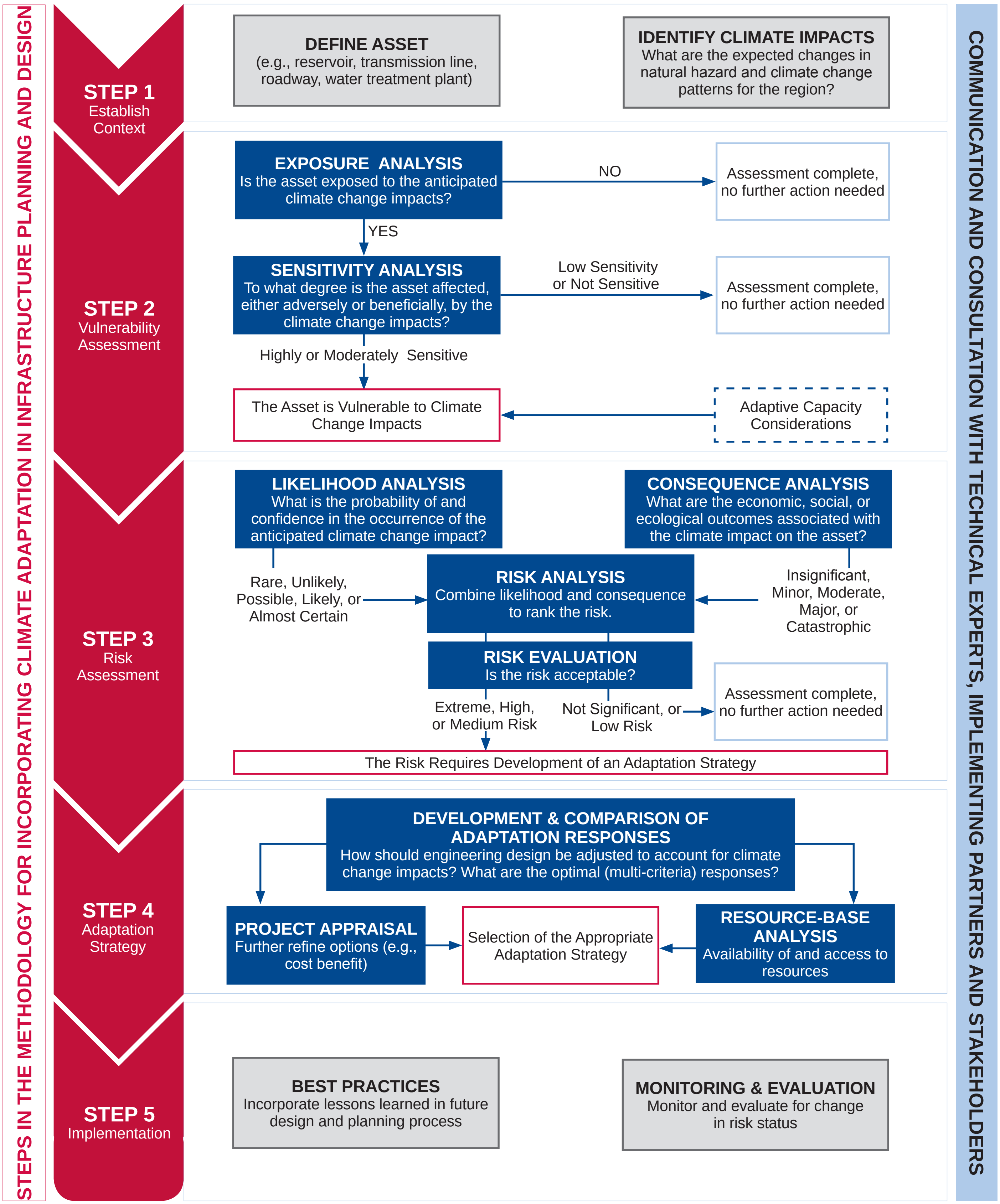
5 STEP PROCESS

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

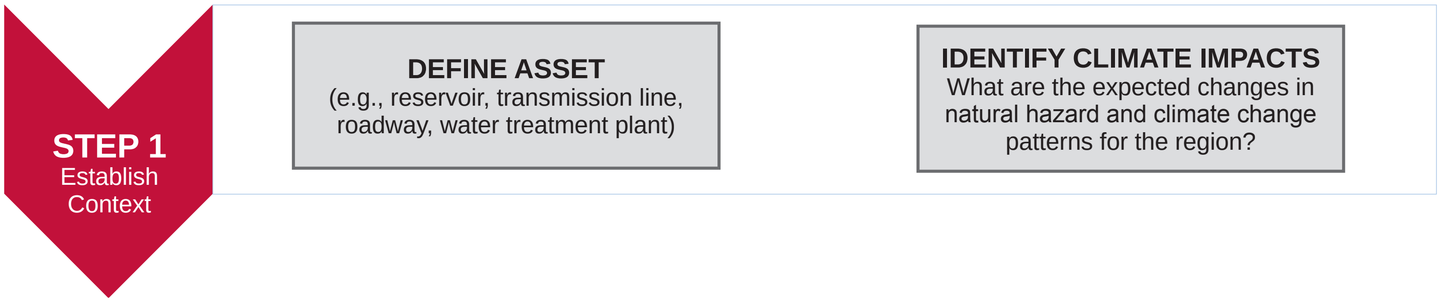
Collectively, these steps establish a climate resilient design methodology to be used when determining appropriate engineering design actions for more climate resilient structures.

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 sanitation infrastructure, and identifying the sources to be tapped within the context of future climate change.

DEFINING INFRASTRUCTURE OBJECTIVES

For sanitation infrastructure, it is important to review the likely future per-capita service requirements. Understanding projected demand 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 for a sanitation system will change accordingly.

Consideration should also be given to the broader system that the assets are integrated with. Once the scope of the assets is defined, information about the assets is 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).

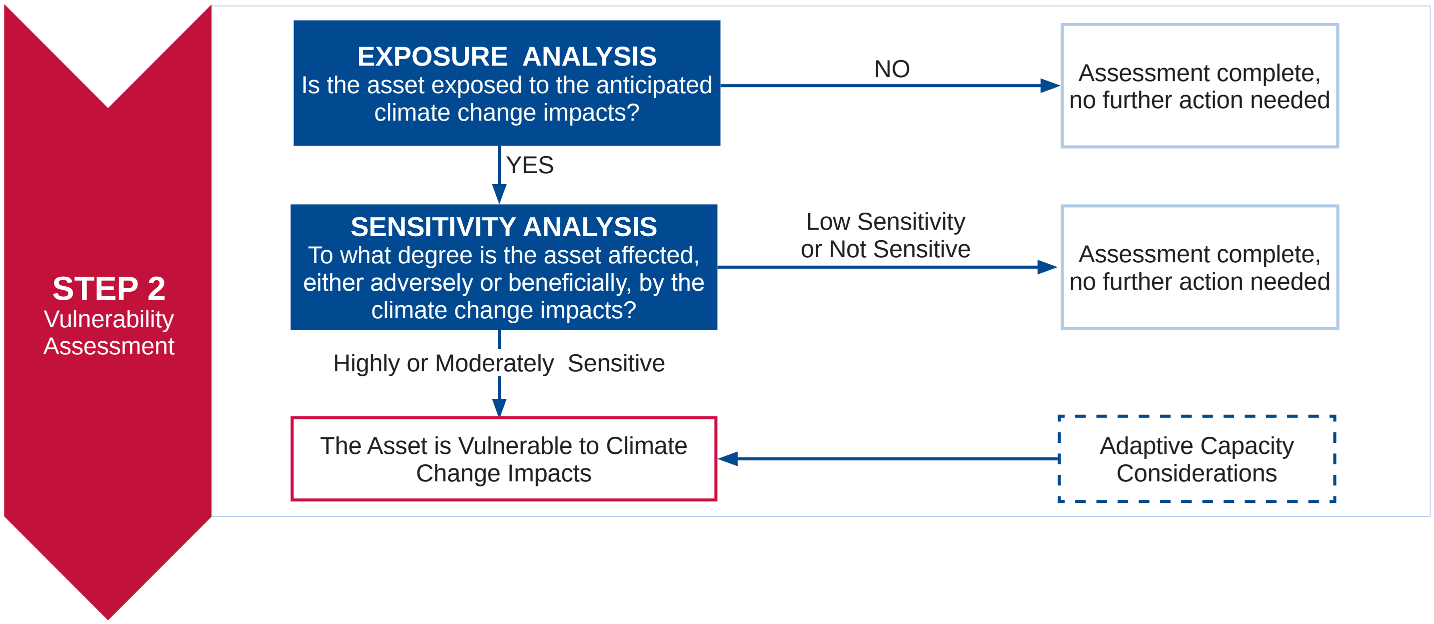
Most of these factors will be reviewed as part of typical planning infrastructure development activities. The additional element that must be integrated involves climate science modeling for the region to understand what the likely changes in climate variables such as rainfall patterns, extreme temperature, 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.

STEP 2: VULNERABILITY ASSESSMENT



CONDUCTING A VULNERABILITY ASSESSMENT

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

2. Analyze sensitivity of the asset using a sensitivity matrix

3. Consider adaptive capacity

The second step in the overall approach considers the degree to which an infrastructure asset is susceptible when exposed to hazards identifying those that warrant more detailed investigation in Step 3.

The vulnerability screening involves understanding an asset's vulnerability to specific climate change impacts over time. *Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change*[2] (USAID, 2014) defines vulnerability as a function of an asset's exposure, sensitivity and adaptive capacity to a specific climate hazard.

DETERMINING ASSET EXPOSURE

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

For each planned activity, determine whether or not it is likely to be exposed to the impacts identified in Step 1. Spatial information related to hazards will assist this process (e.g. flood hazard or other planning maps). Only those assets deemed to be exposed 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.

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

For example, a substation at a wastewater treatment plant may be more sensitive to flooding than submersible mechanical equipment because substations are not designed to operate while inundated. In addition, water supply services are likely to be more sensitive to reductions in average precipitation than wastewater treatment services, because rainfall is not a key input into the wastewater treatment process, however, rainfall is a critical source of water for many regions. Table 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 • Some minor restoration work required
MODERATE Sensitivity	• Widespread infrastructure damage and service disruption requiring moderate repairs • Partial damage to local infrastructure
HIGH Sensitivity	• Permanent or extensive damage requiring extensive repair

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

TABLE 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
Wastewater and Sanitation	Latrines	LOW	LOW	MODERATE	HIGH	HIGH	MODERATE	MODERATE
	Septic, Leach Field Systems	NOT	LOW	LOW	HIGH	HIGH	NOT	LOW
	Sewerage Assets	NOT	MODERATE	MODERATE	HIGH	HIGH	NOT	LOW
	Wastewater Treatment	LOW	LOW	LOW	HIGH	HIGH	MODERATE	MODERATE

NOT Sensitive   LOW Sensitivity   MODERATE Sensitivity   HIGH Sensitivity

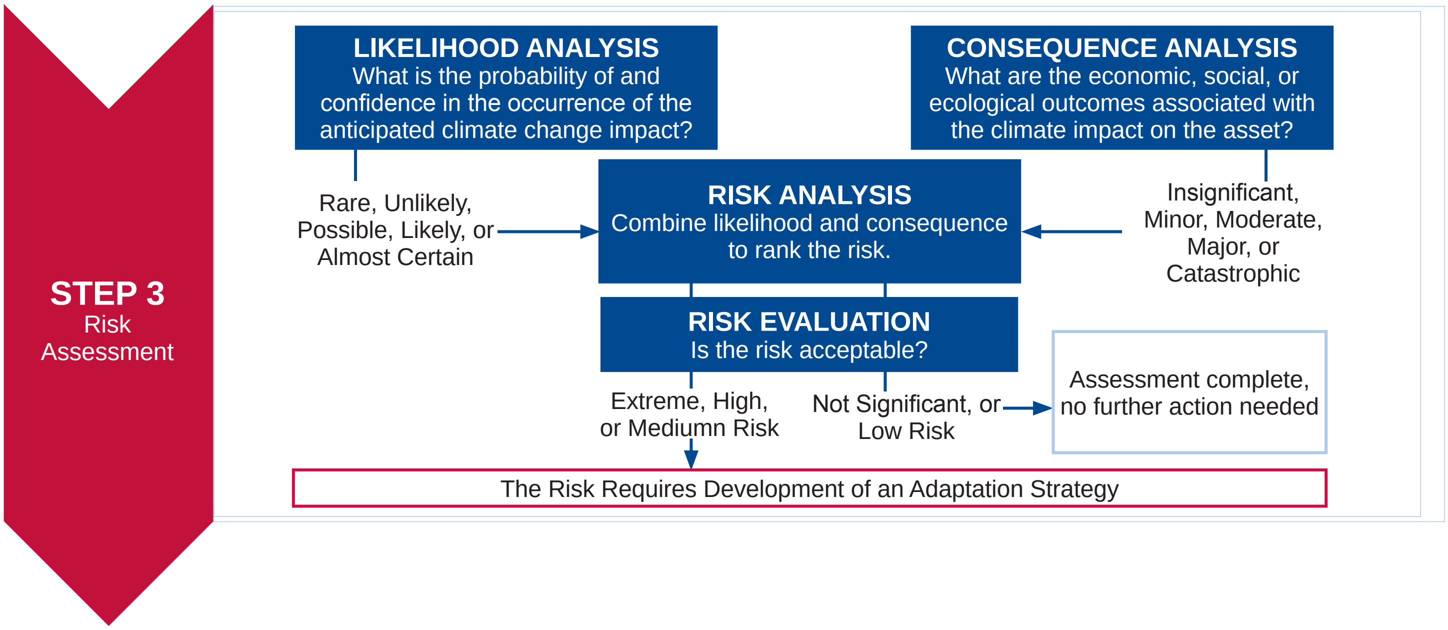
ASSESSING ADAPTIVE CAPACITY

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.

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

CONDUCTING A RISK ANALYSIS

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

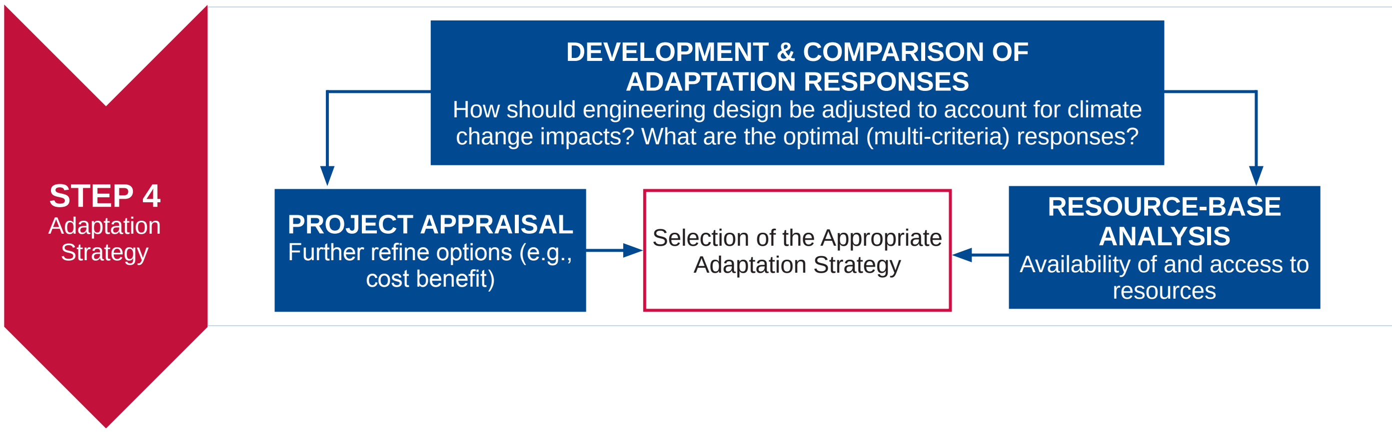
Level of Risk	Definition
EXTREME ≥ 20	• Extreme risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations • These risks are not acceptable without treatment
HIGH 12-16	• High risks are the most severe that can be accepted as a part of routine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

DETERMINING RISK ACCEPTABILITY AND THE NEED FOR ADAPTATION

Based on the outcomes of the risk analysis, it is necessary to determine and prioritize those risks requiring treatment with appropriate adaptation measures. Risk acceptability criteria need to be defined (refer to Table 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 sanitation 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*.

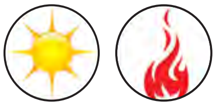
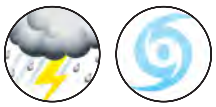
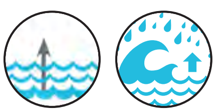
TABLE 9: APPROACH TO ADAPTATION STRATEGIES

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

TABLE 10: ADVANTAGES AND DISADVANTAGES OF ADAPTATION APPROACHES

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

TABLE 11: EXAMPLES OF ADAPTATION OPTIONS FOR CLIMATE RESILIENT SANITATION INFRASTRUCTURE

 Drought, Reduced Available Water, Wildfires	• Low water availability could increase the concentration of sewage sludge at the treatment plant; low flows may require alternative methods to flush out sewers • Design outfall pipes for treated wastewater to be reused for agricultural or irrigation uses or to supplement gray water for toilet flushing • Replace latrines with dry or composting latrines which provide increased odor control • Location of sanitation systems should be selected to minimize impacts of fugitive emissions and odor due to extreme heat and drought • Maintain and implement vegetation management practices that aim to minimize fire risk
 Extreme Precipitation Events, Less Frequent but Higher Intensity Storms, Flooding	• Design sewage system with inclusion of changing precipitation projections • Size drain and stormwater systems with a consideration of climate change projections. If no projections are available, include a precautionary allowance in the design to provide a safety buffer • Redesign combined sewer systems and install more sustainable urban drainage systems that include water sensitive design and green infrastructure to reduce runoff • Decentralized systems can reduce impact on drainage and sewerage collection systems • Planning of retention and safety basins to avoid overflow to the drainage network and pollution spills downstream • Integrate flood management procedures (forecasting and early warning systems) in sewer and landfill operational planning • Elevate mechanical and electrical equipment in operations or maintenance facilities • Pit covers that seal may keep fecal material from contaminating the floodwater during an extreme weather event. Site sanitation systems that can flood further from the water supply than would normally be necessary. Consider dry or composting latrines as an alternative, as the fecal sludge is less mobile • To reduce the risk of inundation of the septic tank itself or failure of the soak away system during extreme weather events, install non-return valve that can be closed in the event of a flood and do not use the tank until floodwaters have receded • Regular maintenance to reduce sludge buildup can also mitigate damage in a flooding event • Aboveground chambers instead of underground pits can reduce environmental contamination from feces migrating from the pit during a flood event; after flooding, pit needs to dry out in order to restart composting function • Sewerage management site should be large enough to accommodate waste for the operational life of the facility and placement should account for potential flooding from extreme weather events such as heavy precipitation and storm surge (if coastal)
 Sea Level Rise and Storm Surge	• Relocate asset to an area of lower risk • Create a barrier to protect against future sea level rise - build or raise levee, floodwall, revetment, bulkhead, riprap, create and enhance wetlands, undertake beach nourishment • Construct offshore breakwaters • Install storm surge barriers • Use green engineering measures such as mangrove and reef rehabilitation to increase shoreline protection and storm surge buffers • Review location of outfall pipes (in relation to potential backflow) • Latrine collapse from inundation or erosion may be prevented with improved pit latrines, additional planting, soil compaction, and flow diversion • Regular maintenance to reduce sludge buildup can also mitigate damage in a flooding event

STEP 5: IMPLEMENTATION

IMPLEMENTING THE ACTIVITY

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

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

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

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

MONITORING AND EVALUATION

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

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

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

IMPLEMENTING BEST PRACTICES

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

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

COMMUNICATION AND CONSULTATION

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

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

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

Monitoring and evaluation are critical components for project success. For wastewater and sanitation processes, monitoring technologies can help prevent disruptions to treatment systems, maintain compliance with discharge limits, and save energy and chemicals used by maximizing efficiency.

USAID ECO-ASIA


DONOR PROJECT

SUGGESTED RESOURCES

General Resources for Sanitation Design

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Charles, K., Pond, K. and Pedley, S. “Vision 2030: The Resilience of Water Supply and Sanitation in the Face of Climate Change, Technology Fact Sheets,” Robens Center for Public and Environmental Health, University of Surrey and the World Health Organization, available at http://www.who.int/water_sanitation_health/publications/vision_2030_technology_fact_sheets.pdf, accessed May 13, 2014.

EOOS and WEDC, “A Collection of Contemporary Toilet Designs, “ WEDC Loughborough University, January 2014, available at http://wedc.lboro.ac.uk/knowledge.

Oates, N., Ross, I., Calow, R., Carter, R. and Doczi, J., “Adaptation to Climate Change in Water Sanitation and Hygiene: Assessing Risks and Appraising Options in Africa,” ODI and DFID, January 2014, also contains a very comprehensive bibliography of further related reading.

IRC International Water and Sanitation Centre, available at http://www.irc.nl/ Since its foundation in 1968, the IRC International Water and Sanitation Centre (IRC) has facilitated the sharing, promotion and use of knowledge so that governments, professionals and organizations can better support poor men, women and children in developing countries to obtain water and sanitation services they will use and maintain. The website contains a vast array of references, training courses and documents. Of particular interest is the interWATER Guide to Organizations

Morshed, Golam and Sobhan, Abdus, “The search for appropriate latrine solutions for flood-prone areas of Bangladesh,” Waterlines Vol. 29 No. 3, Practical Action Publishing, July 2010.

NETWAS: Network for Water and Sanitation. Hosting the International Training Network for Water and Waste Management (ITN - Africa). http://www.netwas.org/ A network of regional and international training institutions, launched in 1984 by the World Bank’s Water and Sanitation Program to support training in low-cost water supply and sanitation. ITN Centers provide training, disseminate information and promote local applied sector research on low-cost water supply and sanitation options. The Network links affiliated institutions serving Asia and Africa in Ouagadougou, Burkina Faso (serving countries in francophone West Africa); Kumasi, Ghana; Harare, Zimbabwe; Nairobi, Kenya; Ethiopia; Tanzania; Uganda; Dhaka, Bangladesh; Calcutta, India; and Manila, Philippines. New centers are under development.

National Institute of Standards and Technology (NIST). 2015. Community Resilience Planning Guide for Buildings and Infrastructure Systems, Special Publication 1190, http://www.nist.gov/el/building_materials/resilience/guide.cfm

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USAID Knowledge Services Center, Sandra Kong, M.P.H., and Marcia Brown, M.A., “Best Practices and Lessons

Learned from Sanitation Programming at USAID: An annotated bibliography," March 2009. Water and Sanitation Program Knowledge Network http://www.wsp.org/

USAID, "Operations Manual on the Rules and Regulations Governing Domestic Sludge and Septage," available at http://www.waterlinks.org/, June 2008.

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

Water Supply and Sanitation Collaborative Council, available at http://www.wsscc.org/ Established in 1990 at the end of the International Drinking Water Supply and Sanitation Decade. Its purpose is to maintain the momentum of the Decade, by providing a regular way for water and sanitation sector professionals to exchange views and experiences and develop approaches to foster more rapid achievement of the goal of universal coverage.

WELL Research Centre Network for Water, Sanitation and Environmental Health, available at http://www.lboro.ac.uk/well/ The WELL website is a focal point of information about water, sanitation and environmental health and related issues in developing and transitional countries. They publish a wide-variety of guidance documents, including factsheets, studies and technical briefs.

WHO, "Summary and Policy Implications Vision 2030: the resilience of water supply and sanitation in the face of climate change," 2009.

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SANITATION CLIMATE CHANGE ADAPTATION STRATEGIES

ANNEX

INTRODUCTION

This Annex, *Sanitation Climate Change Adaptation Strategies*, is a companion to *Sanitation: 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).

Of the small-scale solutions to sanitation, septic tanks can be appropriately designed for a range of conditions, from very small residential applications to very large industrial applications. Largely designed for providing only primary treatment of wastewater, these have the advantage of providing decentralized on-site treatment and are generally lower cost than connecting to a larger wastewater collection and treatment network. Improved pit latrines, composting and dry latrines complete the range of common small-scale sanitation solutions. All of these types of sanitation require additional planning and maintenance for emptying and disposal of septage.

On a larger scale, usually urban sanitation services are rendered through sewerage. The collection of wastewater from individual households and industry is conveyed through shared piping to a treatment plant. Treated wastewater is either disposed of, or reused. Septage also requires disposal.

Adaptation options relevant to both small-scale and large-scale sanitation infrastructure are included in this Annex, and policy and water management strategies are also introduced. 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.

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SEPTIC TANKS

TABLE A.1: SEPTIC TANKS OPTION - INSTALL NON-RETURN VALVE

Overview	
	Installation of a non-return valve just before the septic tank inflow allows the user to close the tank inlet to external floodwater in the case of an extreme weather event. The septic tank could not be used while floodwaters are high, but could be opened once the floodwater receded.
Advantages	• Low-cost manual control allows continued use of an existing system in variable climate scenarios • Lowering incidence of siltation and flooding of an underground septic system
Disadvantages	• Does not address the underlying vulnerability in the design of septic tanks • Requires plumbing capability • Requires manual control prior to flood onset, which may not be possible
Indicative Costs	• Purchase non-return valve • Install valve at septic tank inlet • Trained personnel to close valve prior to extreme weather
Timing for Implementation	• Immediate
Governance	• None
Acceptability	• High acceptability
Feasibility and Technical Requirement	• Valve installation can be done with locally available inputs and labor • Existing local skills associated with current facilities can be used for operational purposes

TABLE A.2: SEPTIC TANKS OPTION - SITE TANK FURTHER FROM WATER SUPPLY

Overview	
	When the climate scenario includes more frequent flooding or rising groundwater levels, the design standards can be modified to increase the distance between the septic system and a water supply source. This distance may reduce the likelihood that damage to the tank from flooding or flotation will cause environmental contamination, though the tank or soak-away system may still be damaged.
Advantages	• Prevents expense of decontaminating or finding an alternative water source • Increased protection of supply and water security
Disadvantages	• May not prevent damage to the system • Alternative locations for the septic system may not be available • Only appropriate during initial design or replacement of an existing tank
Indicative Costs	• May require additional underground land rights • Length of disposal pipeline may increase relative to original design
Timing for Implementation	• No additional time required compared to a previously designed septic tank • 1-3 months for septic tank and soak-away construction, depending on size of the facility
Governance	• Small infrastructural projects require local municipal or district approvals
Acceptability	• High acceptability where impact on local communities is low • Conflict may arise if septic tank location is within range of a neighbor's water source, as might occur in an urban area
Feasibility and Technical Requirement	• Relocation of an existing septic tank or construction of a new one will also require investigation of the water and wastewater users within the local watershed, perhaps up to a 1 km radius. Will require specific engineering inputs for design and construction as well as relevant materials (i.e., not local materials) • Existing local operation and maintenance skills associated with current facilities can be limited.

TABLE A.3: SEPTIC TANKS OPTION - PLANT VEGETATION

Overview	
	All on-site sanitation options will benefit from this adaptation option, which can be targeted to adsorb stormwater runoff, treatment, control erosion, and to some extent, attenuate and divert floodwaters. Exploration includes key phases of preliminary and detailed surveys to discover: • Identification of drainage patterns and their characteristics; and • Identification of locally adapted water loving plants (for planting above shallow soak away pits) and local drought tolerant plants (for planting along existing drainage channels and around proposed drainage structures to reduce erosion and attenuate flooding).
Advantages	• Typically will have low installation and maintenance costs • Can improve aesthetics of a facility • Compatible with existing infrastructure
Disadvantages	• Installation may need to be adapted further as changing climate conditions become more clear • Some CAPEX and OPEX required, including operation and maintenance costs, and costs associated with monitoring for adequate treatment
Indicative Costs	• Hydraulic study of site • Identification and acquisition of appropriate plant species • Installation • Initial watering until established and continued pruning and maintenance may be required
Timing for Implementation	• 1-3 months for study, depending on size of site • 1-2 weeks for installation prior to rainy season, if relevant • 6 months to establish planting and make adjustments if necessary
Governance	• Relevant funding body and engineering units • Public consultation if plantings will be on a public site such as a hospital or community center
Acceptability	• Moderate to high level of acceptability as limited disturbance to community. • Concerns regarding sustainability of resource and safety if plants become overgrown and provide cover for criminal activity
Feasibility and Technical Requirement	• Requires moderate hydrogeological, engineering and botanical expertise (local procurement) • Requires basic skills for operation and maintenance tasks, local training investment

TABLE A.4: SEPTIC TANKS OPTION - EMPTY TANK MORE FREQUENTLY

Overview	
	To mitigate the risk of siltation, flotation or damage to underground septic tanks due to increasingly frequent storms, a preventative maintenance schedule, such as scheduling more frequent tank emptying, particularly in urban areas, can help to mitigate damage.
Advantages	• Can reduce CAPEX cost of re-siting and rebuilding septic tank that has been damaged due to flotation
Disadvantages	• Increased OPEX costs from more frequent emptying • Increased septage volume from disposal, could reduce treatment effectiveness of septic tank
Indicative Costs	• Cost of emptying, depending on current and increased schedule
Timing for Implementation	• Immediate
Governance	• Indirect governance impact of increased septage disposal needs
Acceptability	• Likely to be highly acceptable to nearby users • Could increase septage management loads
Feasibility and Technical Requirement	• Requires no additional technical expertise

TABLE A.5: SEPTIC TANKS OPTION - FLOOD AND EROSION CONTROL STRUCTURES

Overview	
	Perhaps best used in conjunction with planting appropriate vegetation, installation of low impact flood and erosion control structures can be part of a larger integrated water resources approach to decreasing impacts of climate variability and improving site performance in extreme weather conditions. Not intended to be large-scale, these are small bunds, dykes, levees and groins that attenuate flood flows and redirect water around or away from the septic field. Care must be taken to understand water flow under extreme weather conditions on the site, at least conceptually, and with small-scale interventions, iterate until flood flows are successfully attenuated on site, and flows redirected from the soak away system and from the septic tank inlet.
Advantages	• Used to redirect or attenuate flood flows • Reduces flood damage
Disadvantages	• If not done carefully, can cause unintended damage to areas where water is now diverted, or standing water where it was not intended
Indicative Costs	• Hydraulic study of site (can be combined with study for plantings – refer to Table A.3) • Cost for design and construction is site specific, but for individual homes could be entirely implemented by property owner with limited technical assistance • May be some iterative costs as performance is tested
Timing for Implementation	• 1-3 months for study, depending on size of site • 1-2 weeks for installation prior to rainy season, if relevant • 6 months to test and make adjustments if necessary
Governance	• May require local permits to ensure that neighboring properties are not damaged • Public consultation advised if there are possible impacts to neighboring property
Acceptability	• Moderate to high level of acceptability as limited disturbance to community • Concerns regarding sustainability of resource and safety if installations are not maintained or cause major changes in water flow patterns
Feasibility and Technical Requirement	• Requires minor engineering and construction management expertise (most likely provided through local technical assistance, with construction provided by individual landowners or occupants) • Requires some skills for maintenance tasks (requires training of local personnel)

PIT LATRINES

TABLE A.6: IMPROVED PIT LATRINES - INCREASE WATER CONSERVATION

Overview	
	As sanitation infrastructure moves higher on the sanitation ladder, the ladder tends towards sanitation solutions that require ever more water. Water is used for cleansing, then flushing, and eventually, sanitation tends towards waterborne collection systems that transport waste to centralized treatment facilities. One strategy for adaptation, when the system is vulnerable because of an over-dependence on water use, is to reduce water use. In-home composting toilets, waterless urinals and tiger toilets are examples abound of water conserving sanitation solutions. Also gray water recycling strategies such as those discussed in Table A.10 could be used as adaptation strategies for reducing sanitation system's dependence on a readily available water supply that may become more and more stressed.
Advantages	• Technology is flexible and adaptable to a very wide variety of conditions • Improved systems will reduce pressure on water resources • OPEX typically minimal • Highly decentralized – improved self-sufficiency
Disadvantages	• Upgrade requirements will vary between households, increasing project complexity • Will only have an effect with widespread uptake • Moderate CAPEX • Lack of capacity or willingness for residents to manage their own decentralized form of waste disposal
Indicative Costs	• Significant time costs associated with review of individual households • Loan guarantees or private sector vendor training if they will provide the water conserving infrastructure • Cost of alternative pit conditions or proprietary water conserving latrine structure, may include alternate plumbing if gray water is used
Timing for Implementation	• 2 - 3 months for review of existing infrastructure • Upwards of 12 months for upgrade and installation of new infrastructure • Time-frames highly dependent on specific community requirements
Governance	• Composting toilets and gray water policies not including in the policies in many countries • Intervention with primarily local benefits • Stakeholder consultation and public participation are key
Acceptability	• Some public opposition may occur to what is not considered a mainstream technology • Uptake likely to be dependent on existing culture of water conservation, actual operations and maintenance requirements of different technologies • Potential aversion to new technology or inability to foresee return on upfront costs • Additional water conservation measures may be more cumbersome to install if it is difficult for a family to see the collective benefit
Feasibility and Technical Requirement	• Composting toilets 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.7: IMPROVED PIT LATRINES - SHALLOWER, SMALLER PITS WITH MORE FREQUENT EMPTYING

Overview	
	In the case the changes in water availability bring a decrease in water table depths, the rising water table has potential environmental contamination risks for underground pits. An adaptation strategy to consider in this case is decreasing the depth and overall volume of the pit itself. This strategy can also help to offset the environmental contamination risks of more frequent or more severe flooding, as a shallower, smaller pit will hold less septage volume that can potentially contaminate floodwaters, and deposit in living areas of flood affected people. This strategy will not negate the risk entirely, though. In most cases, a smaller, shallower pit will also mean emptying the pit more frequently, as the design holding volume will be lower. More frequent emptying may be feasible in urban settings, where cart drawn septage handling ("the gulper" developed by Water for People is an example) is most appropriate and can be done by small-scale entrepreneurs with low cost equipment. For the success of this approach, licensing and a supportive enabling environment are key factors.
Advantages	• Business opportunity for pit emptying by small-scale entrepreneurs rather than solely by tanker truck • Decreases extent of environmental contamination in floods and extreme weather
Disadvantages	• Enabling environment may not support small-scale emptying • Increased OPEX potential because of more frequent emptying needs, though CAPEX of emptying service is reduced if volumes are not sufficient to support vacuum trucks
Indicative Costs	• Slightly lower cost than traditional latrine because of reduced labor cost for excavation • Small-scale emptying entrepreneurs would need a cart that can haul plastic drums, a septage pump such as "the gulper" and a small truck to transport drums to a septage disposal location • Septage handling license • Septage disposal cost
Timing for Implementation	• Ongoing change to current practice, with full implementation depending on enabling environment for small-scale septage handlers
Governance	• Current licensing environment may not allow for small septage handlers, most laws require septic and latrine septage to be removed by vacuum truck • Finding, training and equipping (likely with micro-loans) entrepreneurs that would provide this service • Changing the local codes and standards (along with local practice) to decrease pit sizes
Acceptability	• Latrine owners may have difficulty with cash flow for emptying, a situation that is only exacerbated • by needing to empty more frequently • No change to CAPEX situation, making it appealing to government and donors
Feasibility and Technical Requirement	• Business and skills training for local labor • Development of low cost portable septage handling that fits the local context

DRY OR COMPOSTING LATRINES

TABLE A.8: DRY OR COMPOSTING LATRINES - MAKE SUPERSTRUCTURE MORE DURABLE, OR CHOOSE A TEMPORARY OPTION THAT CAN BE RAPIDLY REINSTALLED

Overview	
	In the case of a relatively low cost investment such as latrines, often adaptation becomes a difficult choice between additional investment in a more robust and durable structure or accepting that the structures will fail, and planning for replacement. To be a true economic decision, households must be saving or insuring against loss, so that when their latrine structure fail, they have savings to access for replacement, or a fund that helps to mitigate the costs of recovery after disasters. The choice of adaptation strategy might also consider potential human health impacts, such that latrines in dense urban areas are more likely to cause environmental contamination when they fail, whereas rural latrines may be less likely to exacerbate disease outbreaks. In rural areas of developing countries with less access to formal banking, this may take the shape of a rural savings fund, similar to the way a farmer might save for seed or other agricultural inputs. As long as the fund is current, the community could then allow for more temporary latrine structures and pits that are replaced when inundated. For the very poorest communities and households, their “option” is often the cheapest one, and they do not carry the savings to call it temporary. Donors and governments will be called upon in disasters to assist these families.
Advantages	• Flexibility to consider very local impacts and ability to save and pay • Decrease in replacements and environmental contamination in the case of a more durable structure • Low replacement cost, in the case of a temporary structure
Disadvantages	• Requires investment in savings banks or micro insurance funds, which may be difficult to prioritize • High potential for contamination in the case of failure, for a temporary structure • High cost of initial installation compared to traditional designs, in case of more durable structure
Indicative Costs	• Slightly higher cost than traditional latrine for additional robustness of structure (reinforcing steel, pit lining extending above ground level, cross bracing for wind resistance in extreme weather • Lower cost temporary structures could be made from fiber reinforced tent plastic (tarp) or locally woven reed mat on a PVC or light wood frame
Timing for Implementation	• 4-12 months
Governance	• Building codes that allow for temporary structures, or require more durable structures • Support to communities and individuals that do not yet have the ability to save for future disasters
Acceptability	• Low level of input and management required after initial construction
Feasibility and Technical Requirement	• Basic design, architectural and construction support • Train locals with construction techniques • Basic O&M required for sustainable system use

SEWERAGE AND PIPED COLLECTION SYSTEMS

TABLE A.9: SEWERAGE AND PIPED COLLECTION SYSTEMS: SUSTAINABLE URBAN DRAINAGE SYSTEM AND SEPARATE SEWERS

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. 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. Water shortages are a key issue driving innovations in treatment technology. The cost of wastewater treatment increases with increases in 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: • Developing and improving performance of treatment membranes to maintain water quality; • Efficient recovery of resources from water and wastewater streams; and • Water quality assurance for consumers of water and treated wastewater. There is evidence to show that a variety of options are feasible for use of wastewater treatment in the developing world and that many low-technology options can be mixed and matched for very high efficiencies, such as natural treatment technologies.
Advantages	• Working towards a solution to water scarcity problems • Cost effective for future energy demands
Disadvantages	• High investment cost of conventional systems prohibitive • Plant requires energy to pump the waste around • Mental opposition to drinking treated wastewater • Potential for wastewater recycling loops and subsequent contamination
Indicative Costs	• Variables include: scale of system (volume being treated), standard of output, consistency of inputs • Upfront costs
Timing for Implementation	• Large-scale (municipal) system: 6 months to a few years • Small-scale (community) system: 2 months to a year
Governance	• Large-scale (municipal) system: requires significant public investment • 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.10: SEWERAGE AND PIPED COLLECTION SYSTEMS - GRAY WATER RECYCLING FOR TOILET FLUSHING, RAINWATER COLLECTION

Overview	
	Reducing the treated potable water that is necessary for on-site toilet flushing and on-site irrigation can greatly reduce the energy and water requirements of a piped sewage treatment system, and can save individual property owners money. As increasing operations and maintenance costs and water stresses impact centralized systems, the loss of household level revenue should be seen as a long term investment in reduced capital costs. Gray water recycling for lower tier uses such as toilet flushing will require additional plumbing at established sites and alternative plumbing networks at new sites, but reduces water use overall. Rainwater collection can be used to supplement gray water reuse, or can be used for irrigation in dry periods.
Advantages	• Working towards solution to water scarcity problems • Cost effective for future energy demands • At high adoption rates, can reduce capital investment needs
Disadvantages	• Reduced revenue from water sales and wastewater treatment fees for the centralized utility • Mental opposition to use of untreated wastewater • Requires individual investments on private property, which can be harder to incentivize and track
Indicative Costs	• Split plumbing installed to capture and reroute gray water • Upfront costs on installing rainwater capture and distribution tank or tanks
Timing for Implementation	• Each household could implement changes in plumbing and installation of rainwater capture in 2-3 months. Large-scale adoption of the technology may take years
Governance	• Local laws may not allow for split plumbing systems to reuse gray water • Requires community buy in and ongoing investment in maintenance
Acceptability	• Highly acceptable at community and government scales, but requires individual investment, contracting with local service providers • May require a campaign or stipend to incentivize participation
Feasibility and Technical Requirement	• Relatively low tech, rainwater capture can be done on the household level with a minimal level of plumbing skills • Gray water recycling may require a slightly higher level of hydraulic and plumbing knowledge to be done correctly

TABLE A.11: SEWERAGE AND PIPED COLLECTION SYSTEMS - CONSIDER DECENTRALIZED WASTEWATER SYSTEMS FOR TOILET FLUSHING, RAINWATER COLLECTION

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. 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. Decentralized systems, such as those implemented at the community level or at the facility level may be more appropriate and more resilient in a changing climate. In cities, individual neighborhoods could collect their sewage into a smaller scale anaerobic digester that generates methane and other gases that can be used for cooking or for process heating or other energy needs. In rural areas, the same can be done at facilities that have high resident or daytime transient populations such as schools and hospitals. Even in cities, decentralized sewage treatment can reduce the investment needed for adequate sanitation. Smaller facilities may be more resilient to sea level rise and changing water flow patterns.
Advantages	• May reduce water needs for wastewater conveyance • May increase resource recovery, such as wastewater to energy • Can reduce energy needs for pumping
Disadvantages	• Combined costs of all systems may be higher than one centralized treatment works • May increase operations and maintenance costs in areas where labor costs are high
Indicative Costs	• Variables include: scale of system (volume being treated), standard of output, consistency of inputs • Upfront costs
Timing for Implementation	• Large-scale (municipal) system: 6 months to a few years • Small-scale (community) system: 2 months to a year
Governance	• Large-scale (municipal) system: requires significant public investment • 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.12: SEWERAGE AND PIPED COLLECTION SYSTEMS - EMERGENCY RESPONSE EQUIPMENT INSTALLATION, SUCH AS OFF SITE, REDUNDANT PUMPS, AND GENERATORS

Overview	
	Addressing the need for water and sanitation systems to remain functional in more frequent extreme weather events may require a revision of disaster and contingency plans. In the case that pumps or generators are found to be vulnerable to a changing climate, such as sea level rise or more frequent flooding, a sewerage management agency may need to consider additional capital expense of the off-site or redundant pumps and off-site backup generators. Planners may want to consider a changed scenario in existing emergency or contingency plans, and increase the diversity of options should part of the system become inundated or unusable. Shortly following an extreme weather event, sewage conveyance and wastewater treatment should return to close to normal functioning to protect public health and guard against environmental contamination. To achieve this, systems may need to plan for additional pumping capacity and backup generation at locations that are less vulnerable to flooding.
Advantages	• Working towards better, more reliable service delivery in uncertain conditions • Generally more cost effective to prevent failures than to react to them
Disadvantages	• Requires planning additional capital expenditures that may not already have been in the long term plan • Uncertainty about the effects of climate change on critical assets may lead to difficult trade-offs or unclear options
Indicative Costs	• Variables include: scale of system (volume being pumped, energy requirements), locations of existing infrastructure • Additional pumping capacity • Capital cost of additional back up generators • Testing, operation and maintenance costs of back up or redundant systems to ensure that they operate correctly when needed
Timing for Implementation	• Large-scale (municipal) system: 6 months to a few years • Small-scale (community) system: 2 months to a year
Governance	• Large-scale (municipal) system: requires significant public investment • Small-scale (community) system: requires community buy in and ongoing investment in maintenance
Acceptability	• May require a cost-benefit analysis to show that the additional investment is warranted given the variations expected and the savings potential to avoid a failure or loss of service
Feasibility and Technical Requirement	• Highly dependent on scale of the system

WASTEWATER TREATMENT FACILITIES

TABLE A.13: TREATMENT MEASURES - REDESIGN TREATMENT PROCESS FOR CHANGED TARGET WASTEWATER CONCENTRATION

Overview	
	In regions where increased temperature, drought and water availability can lead to more concentrated wastewater streams, engineers and system planners may need to consider redesigning the treatment process to handle a changed target wastewater concentration. The latest development of water and wastewater treatment technology provides opportunities to improve the resilience of treatment facilities in addition to quality and efficiency improvements. These include: • Organics removal; • Bacterial treatment and disinfection; • Reduction of membrane fouling; and • Improvements in salt removal. 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 desalination and water reuse more affordable to water supply and sanitation services providers. Not only can energy be saved, but there is also the potential to turn wastewater treatment plants into renewable energy producers (Bloom and XPV Capital Corporation, 2010). The proper balance of treatment performance and demand requirement needs 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 • Shift towards non-traditional water sources for specific sectors • OPEX reduced over time
Disadvantages	• Does not address supply issues or pollution and contamination points • High CAPEX and OPEX for creation of new treatment systems
Indicative Costs	• Rebuild and upgrade of existing plant • New membrane bioreactor system
Timing for Implementation	• 12 months for technology installation • 2-4 years for new plant rebuild
Governance	• Utilities and respective engineers for the improvement of existing structures. No community involvement necessary • 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 • Favorable by utilities where operational costs can be reduced through efficiency
Feasibility and Technical Requirement	• Relevant local utility operators needed for consultation • O&M training of locals needed for new technology types

DISPOSAL AND REUSE OF TREATED WASTEWATER

TABLE A.14: WASTEWATER DISPOSAL AND REUSE OPTION - WATER REUSE

Overview	
	Use of reclaimed water is an increasingly common response to water scarcity in many parts of the developed world. Reclaimed water is being used directly for various non-potable uses, including irrigation, commercial uses such as vehicle washing; industrial use 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. Feasibility of this approach requires investment in treatment facilities and the ability to redirect water back through existing pipe systems. Centralized systems are often viewed as uneconomic, making decentralized or on site facilities more viable (Leverenz & Asano, 2010). 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 developing nations (Massoud, et al., 2009).
Advantages	• Maximizes benefits gained from unit of water before moving downstream • Conserves potable water supply for drinking • Limits stress on water cycle
Disadvantages	• Location of treatment facilities and location of users may be large • Health concerns and general public discontent • Additional energy input for treatment and re-distribution • High CAPEX and OPEX for centralized facilities
Indicative Costs	• Centralized system total capital cost • Total operation cost • Alternative decentralized gravity system total capital cost • Total operational costs
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 • Public-Private coordination for large-scale reclamation schemes • Utilities providers for approval and existing infrastructure • Public consultation to improve acceptability, educate levels of use for quality
Acceptability	• Public disapproval based on quality concerns • Increases energy and input needed for water treatment • More acceptable in areas of low water security
Feasibility and Technical Requirement	• Utilizes existing infrastructure but can require engineering of new distribution channels • Some private-public partnership for large projects with high CAPEX • Existing OPEX used, training of locals on standards, and quality required

POLICY AND PLANNING

TABLE A.15: 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 who 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: • Legal Framework: a system of legal frameworks that stipulate rights and responsibilities (e.g., wastewater treatment, disposal permits); • Institutional Strengthening: build operation and management capability for related institutions of national, regional and local levels; • Policies: Produce policies that guide national, regional, state, local laws; • Clarification and Division of Roles: clearly define role for players (Governments, Ministries, departments, regulators and other authorities); • Development of infrastructure: Build physical wastewater infrastructure: sewerage systems, treatment plants; • Plans of Actions: Develop a set of water management plans with the flexibility to anticipate and respond to climate change; and • Effective Uses and Sharing of Information: Establish a good practice and system for sharing current and projected climate information. 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 (McKenzie and Corfee-Morlot, 2006). 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 as higher-level organizations.
Advantages	• Low CAPEX • Many existing templates to model policy and framework upon • Structure for future projects and long term planning
Disadvantages	• Requires broad government coordination across sectors and levels • Technical knowledge and expertise required • 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 • Dialogue with international governing bodies to ensure criteria and standards addressed
Acceptability	• High acceptability where government communication is good • Does not require tangible outcomes or impacts upon communities
Feasibility and Technical Requirement	• Access to the requisite knowledge, expertise and technical skills • Guidance from experienced climate policy writers • Training of local government staff for policy and framework requirements

**OECD - Organisation for Economic Co-operation and Development*

TABLE A.16: 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. 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 • Provides a framework for consistent implementation and integration of WSUD in new developments • Provides design guidance on WSUD details • Identifies issues that should be considered when evaluating strategies to achieve WSUD • Supplements (but not replaces) existing WSUD regulations and detailed design and implementation guidelines • 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 • Do not take site specific conditions into account, including topography, soils, landscape, services and other relevant site features and structural elements • 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 • WSUD would require involvement from relevant water utilities and their engineering divisions (or external procurement) • Stakeholder consultation is key
Acceptability	• High acceptability – usually WSUD does not result in significant disturbance to local communities • Little public opposition against, and considerable support for, the use of WSUD • 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 • 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 • Existing local skills associated with current facilities can be used for operational purposes • May require advanced plumbing work

**OECD - Organisation for Economic Co-operation and Development*

TABLE A.17: 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 Water Sensitive Urban Design (WSUD) strategy. The following site characteristics should be considered as part of a detailed site analysis: • Climate (rainfall - annual average, seasonal variation); • Topography (steep slopes, vicinity to natural waterways); • Soils and geology (suitability for infiltration); • Groundwater (depth to water table); • Salinity (acid sulphate soils); • Space (potential areas for water treatment and storage); • Services (conflicts with existing and proposed); • Environmental (significant species); and • Heritage (retrofitting plumbing on heritage listed buildings). 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 • A WSUD strategy would be site and development specific as each site has specific environmental conditions that influence implementation of WSUD
Disadvantages	• WSUD upgrade requirements will vary between households and developments, increasing project complexity • WSUD will only have an effect with widespread uptake
Indicative Costs	• Varies site by site
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 • WSUD would require involvement from relevant water utilities and their engineering divisions (or external procurement if they don't have internal capacity). It does not require involvement from general community • Stakeholder consultation is key
Acceptability	• High acceptability – usually WSUD does not result in significant disturbance to local communities • Little public opposition against, and considerable support for, the use of WSUD
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 • 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 • Existing local skills can be used for operational purposes

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