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TECHNICAL REPORT

ADDRESSING CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE

PREPARING FOR CHANGE



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OVERVIEW

**ADDRESSING CLIMATE CHANGE IMPACTS
ON INFRASTRUCTURE:
PREPARING FOR CHANGE**



ABSTRACT

Infrastructure includes a wide variety of systems that are essential to development priorities—and these assets may be at risk due to climate change. The accompanying set of fact sheets describes the impacts climate change may have on nine categories of infrastructure in developing countries. This overview introduces the common themes related to infrastructure, climate change impacts, and adaptation strategies, and covers the basic terminology and concepts that are used in the fact sheets.

Infrastructure is critical to development program priorities. Because infrastructure can be costly and is often built to last for decades, these assets are uniquely affected by climate change, though impacts will vary across different infrastructure types and locations. It is critical that the potential impacts of climate change be considered as part of overall program and project development. An ongoing process of adaptive management can help decision-makers understand vulnerability, assess climate impacts, identify priorities, and take appropriate adaptation actions.

Infrastructure forms the backbone of society—serving as the foundation for the economic, social, and cultural life of communities and countries. Resilient and reliable infrastructure is essential for the transport of goods and people, and the provision of energy, clean water, commerce, communication, and emergency response to disasters. Yet the risks posed to infrastructure by a changing climate are often not fully considered as these systems are planned, designed, and constructed. Thus, there is an opportunity to give greater consideration to these important concerns.

Infrastructure encompasses a variety of constructed networks and individual structures that are critical elements of vibrant and functioning communities. Infrastructure includes transportation systems, water and waste systems, energy, and communications networks. Often, infrastructure investment is an integral component of a broader development effort—such as food security, agriculture, or public health. This set of fact sheets for nine categories of infrastructure (see box) provides a summary of the impacts climate change may have on these assets in developing countries. The relative importance of different infrastructure types will vary across different regions, countries, and communities.

This overview covers the basic terminology and concepts that are used in the fact sheets, and summarizes the common themes related to infrastructure, climate change impacts, and adaptation strategies. These themes include:

- Importance of infrastructure to developing countries
- Unique aspects of infrastructure in the context of climate change
- Potential impacts of climate change on infrastructure assets and services
- Basic principles for understanding and implementing an adaptive management approach

The nine fact sheets discuss these issues as they apply to each infrastructure type, and summarize strategies that can be employed to prepare for and adapt to potential climate change impacts.

INFRASTRUCTURE CATEGORIES INCLUDE:

- Transportation
- Potable water
- Sanitation systems
- Solid waste management
- Energy systems
- Information and communications technology (ICT)
- Flood control structures
- Cultural heritage assets
- Buildings

INFRASTRUCTURE IS CRITICAL TO DEVELOPMENT PROGRAMS

Development programs and priorities often rely on highly functioning infrastructure to deliver services to those in need and achieve program objectives. While infrastructure may not always be a central component, support for infrastructure development and maintenance is woven throughout many development programs. Infrastructure plays an integral role in achieving core purposes in programs such as Feed the Future (FTF); water, sanitation, and hygiene; economic growth and trade; disaster risk reduction; and urban development. For example, by supporting construction of water infrastructure, USAID and other development practitioners provide potable water to communities around the world. Further, a variety of infrastructure—including disaster response infrastructure such as evacuation, delivery, and response routes; communications channels; community shelters; and health care facilities—can save lives and protect communities.

A specific programmatic example is FTF, which is supported by a range of infrastructure services that enable agriculture development. A strong transportation network allows farmers to access seed and sell their produce to intermediate markets; a reliable water supply is critical for irrigation; energy networks support agricultural processing facilities. These and other infrastructure systems are fundamental to the ability of FTF to advance food security.

INFRASTRUCTURE IS UNIQUELY AFFECTED BY CLIMATE CHANGE

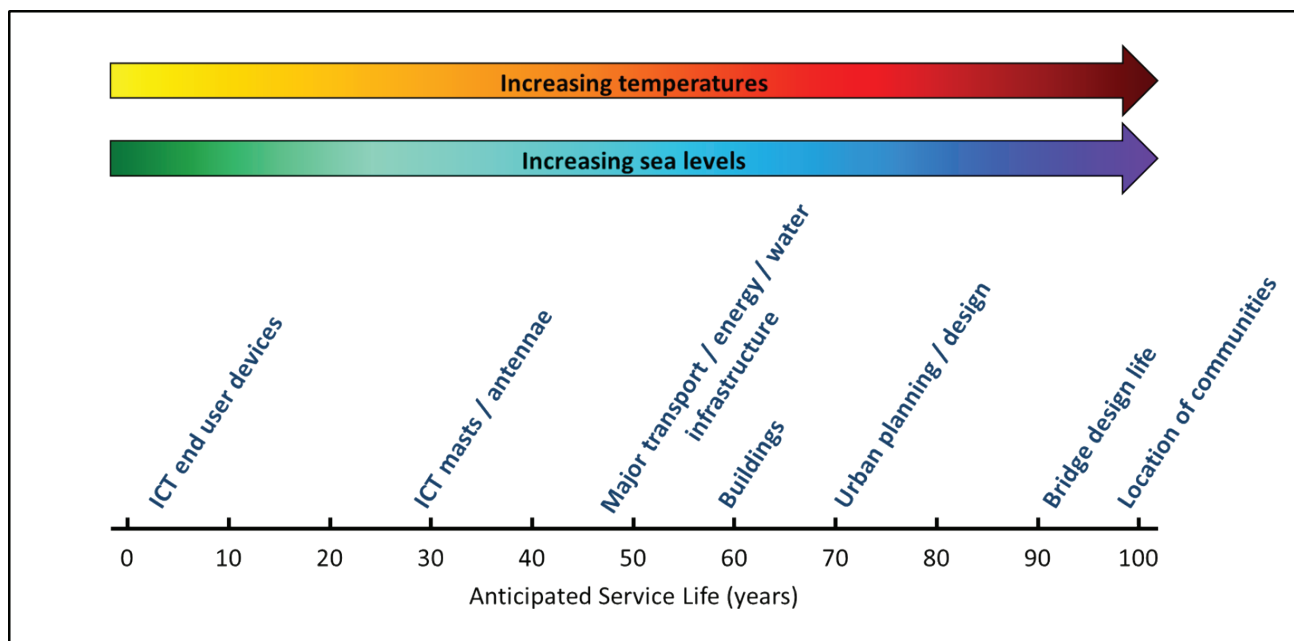
Infrastructure systems are built to last. Once constructed, many types of infrastructure have long lifetimes that span over 20, 50, even 100 years. Some of the most important and useful systems in the world have segments that have lasted more than a century (e.g., railways in India, the subway system in the New York metropolitan area).

While some types of infrastructure are routinely upgraded and replaced, major infrastructure projects—such as bridges, sewer systems, and public buildings—are significant investments that can take many years to plan and build. Once constructed, these systems are often in service for decades and frequently guide local and regional development patterns. **As a result, the infrastructure decisions made today may affect several generations.** Because infrastructure and their services are integral to the economic and social vitality of communities and countries—and because they represent major financial commitments and influence development patterns—it is critical that they are designed and maintained to be low-carbon, resilient, and responsive to the impacts of climate change over time. In general, the longer the anticipated service life of infrastructure, the more important it is to incorporate climate change considerations into planning and design (Figure 1).

In addition, much of **infrastructure is interdependent**. For example, power stations provide energy to help telecommunications systems function, which in turn operate water management systems. Because of this, a disruption in electrical power can have cascading impacts throughout a region. As technology advances, infrastructure is becoming even more interconnected through the introduction of “smart” technologies. For example, use of energy smart grids means that energy infrastructure is reliant on information and communication infrastructure, while the electrification of transportation increases the dependence of transport networks on the power grid. While these advances can support efficiency and reliability across systems, the interdependence of infrastructure underscores the critical importance of using a systems planning approach to avoid and prepare for disruptions, including those due to climate change.

Infrastructure is also uniquely related to climate change in that **the construction, maintenance, and operations of infrastructure significantly contribute to the problem of climate change itself**. Energy, buildings (especially industrial), and transportation infrastructure and operations are key sources of greenhouse gas emissions. Supporting unsustainable infrastructure may give rise to a lock-in effect, whereby

Figure 1. Service Life of Different Infrastructure Types in the Face of Long-term Climate Change¹



¹ Adapted from: AEA, 2010. Adapting the ICT Sector to the Impacts of Climate Change: Final Report. <http://archive.defra.gov.uk/environment/climate/documents/infrastructure-aea-full.pdf>

the influence and dominating factors of the infrastructure in question perpetuates a dependency on fossil fuel use and increases greenhouse gas emissions. This highlights the importance of building sustainable infrastructure that supports low emissions growth.

In developing countries, where a major part of the infrastructure necessary to meet development needs is still to be built, it is essential to consider location, energy use, and connectivity of infrastructure facilities to ensure cost effectiveness, enhanced access, minimal carbon emissions, and increased resiliency in the wake of changing climatic conditions.

THE EFFECTS OF CLIMATE CHANGE ON INFRASTRUCTURE VARY

Climate change is expected to change historical and current climate conditions, including alterations in temperature, precipitation, and sea level, as well as changes in the intensity, variability, and frequency of extreme weather events. Changes in climate stressors will vary across regions depending on specific geo-physical characteristics and other local factors. Further, these changes will have different impacts on different types of infrastructure, depending on the infrastructure function, site, construction, materials, age, and condition. For example, changes in temperature and precipitation will affect fuel extraction capabilities differently than the use of public buildings.

While the direct impacts of climate change on infrastructure warrant significant concern, second and third order consequences may be equally as significant. For example, in certain areas climate change may cause massive migration that will further stress already weak and aging infrastructure in urban areas. As extreme events impact larger areas and populations, information, communication, and technology (ICT) services may be threatened by overuse. Variations in agricultural conditions due to climate change may lead to the relocation of food production, requiring changes in transportation services. Climate change may also increase the need for certain types of infrastructure. For example, climate change is likely to increase the frequency and severity of natural disasters, necessitating additional, more resilient infrastructure for disaster response. Each of the fact sheets provides information on the specific climate impacts that pose the most concern for individual categories of infrastructure.

ADAPTIVE MANAGEMENT CAN HELP DEVELOPMENT PRACTITIONERS PREPARE FOR AND MANAGE CLIMATE CHANGE

Climate change impacts on infrastructure should be considered in a wide variety of development decisions. For example, climate vulnerability should be assessed as national development strategies and sector plans are developed. At the project level, the potential impacts of climate change should be considered in numerous program areas, including water resources, food security, and disaster risk reduction.

As described in the accompanying set of fact sheets, there are numerous ways to prepare for and adapt to changing climate conditions. These climate-resilient development strategies can be tailored to specific conditions at the local and regional-level, and designed within practical fiscal and capacity constraints. Integrating climate considerations into ongoing planning and decision-making processes through a climate-resilient development approach can help USAID and other development practitioners ensure the effectiveness and resilience of their investments in programs, projects, and infrastructure.

Climate-resilient infrastructure development is a process that can be accomplished through the five stages described in USAID's Climate-Resilient Development (CRD) Framework (Figure 2).

Figure 2. USAID's Climate-Resilient Development Framework



Managers can enter this process at any point in the cycle, depending on the status of the program or project under consideration. Together, these five stages form an ongoing and flexible process in which managers can include new information (such as improved climate data or changing socio-economic conditions) and test and refine their adaptation responses. For example, in the *Evaluate and Adjust* stage of an existing infrastructure project, the manager may uncover climate vulnerabilities that were not considered when the project was conceived. In that case, the manager should return to the *Assess* stage to better understand the vulnerabilities, followed by a reconsideration of the *Design* stage to identify approaches to address the vulnerabilities. The adaptation strategies that are selected should be implemented according to the *Implement and Manage* stage.

The underlying concepts in each of the stages are explained below.

SCOPE: ESTABLISH DEVELOPMENT CONTEXT AND FOCUS

SCOPE Effectively managing infrastructure services requires an understanding of the larger context, including the role infrastructure plays in supporting development. Managers can develop this understanding by first identifying how the infrastructure services for which they are responsible are intended to contribute to “big picture” development goal(s) such as reduced hunger; increased physical security, or greater economic prosperity. They should also consider how infrastructure services depend upon and interact with other inputs to those goals and the enabling conditions in which those services are being provided.

For example, an irrigation infrastructure project that is intended to address a national goal to reduce hunger should consider necessary inputs to the project and to the overarching goal including: physical (e.g., water availability), natural (e.g., soil conditions), human (e.g., labor availability to utilize the irrigation system), or economic (e.g., wealth to pay for long-term management of the system). The enabling conditions for the infrastructure

project also need to be considered. In the previous example, the enabling conditions that will determine the ability of the irrigation project to deliver its intended services in the face of a changing climate may include political factors (e.g., policies permitting water transfers), economic factors (e.g., loans to support increased agricultural production), and social circumstances (e.g., the potential for conflict over re-allocation of water resources under conditions of increasing drought).

Next, managers should consider both climate and non-climate stressors that affect these inputs and enabling conditions. For example, climate stressors such as an increased frequency of heavy precipitation events may exacerbate the ability of a sewer system to minimize downstream pollution. Non-climate stressors such as poor maintenance of the sewage system may also inhibit its effectiveness. While identifying these stressors, managers should also identify any associated needs and opportunities that might inform the design of locally-appropriate solutions.

By quickly understanding the development context in the scoping stage, managers can tailor their approach to the subsequent stages of the Climate-Resilient Development Framework. An effective tactic in the Scope phase that can help to inform the aforementioned considerations is to convene a workshop or series of consultations in which relevant decision makers, stakeholders, and experts come together to identify and refine the understanding of the key development goals that are being served, important inputs and enabling conditions, and climate and non-climate stressors that could affect the project's success. In some cases, that scoping dialogue may reveal vulnerabilities that are already particularly acute and where potential solutions are relatively obvious. In those cases it may be possible to move quickly to the **Design** stage to begin to address them. However, in most cases the scoping dialogue's main outcomes will be to help structure an appropriately rigorous vulnerability assessment in the Assess stage, which will be required to inform the design of options to promote climate-resilient development.

ASSESS: ENHANCE UNDERSTANDING ABOUT VULNERABILITY



The potential impacts of climate change vary by location and need to be considered at the regional and local levels. In addition, infrastructure types are differentially vulnerable to climate stressors. Understanding that there is a range of potential futures—with varying climate conditions and associated impacts—is critical to making sound decisions.

Using the context developed in the **Scope** stage, these climate and non-climate impacts can be integrated into a broad view of all the barriers and constraints that may confront development programs. Deciding which infrastructure issues should be addressed first requires a broad view of the relative significance of different infrastructure components within the context of development goals and organizational resources.

As part of the **Assess** stage, practitioners therefore need to both assess vulnerability and set priorities for adaptation.

ASSESS VULNERABILITY

Vulnerability to climate change is defined as the degree to which infrastructure is susceptible to, and unable to cope with, the adverse effects of external climate stressors placed on it. Examples of vulnerabilities specific to each infrastructure type are described in the fact sheets.

Vulnerability is a function of three main components: exposure, sensitivity, and adaptive capacity, with each component affecting overall vulnerability.

Exposure: Exposure refers to the degree to which the infrastructure under consideration (e.g., a port or a wastewater treatment facility) may be subject to climate-related stress. There are two main elements to be considered in exposure: the change in the climate (in terms of the nature, magnitude, rate, frequency, and timing of climate change) and the extent to which that change will have direct impact on a specific infrastructure asset (largely determined by the location of infrastructure in relation to the location of the impact).

Changes in climate can be represented by multi-decade climate scenarios. These scenarios help identify a range of potential changes. Climate scenario information is increasingly available for most regions and provides decision-makers with a basis for assessing the range of impacts that may occur. Climate stressors such as sea level rise, temperature change, and increases in storm intensity then interact with local environmental conditions as well as non-climate stressors, resulting in different impacts in different areas. For example, the impacts of sea level rise on infrastructure will be more severe and cause greater inundation in regions experiencing land subsidence.

Sensitivity: Sensitivity is the degree to which an infrastructure asset or system will be affected or damaged by a climate stressor to which it is exposed. Different infrastructure will be more or less sensitive to the same type and level of exposure. For example, wood can be more sensitive to moisture and wind than cement. As a result, wooden buildings are more vulnerable to floods and hurricanes than cement-based structures.

Adaptive Capacity: In the context of infrastructure, adaptive capacity is the capability or potential to anticipate, prepare for, and respond to potential climate change impacts to an asset, system, or the services that are provided. This includes the ability to moderate potential damages, take advantage of opportunities, or cope with consequences. Core socio-economic drivers—such as access to education and information, wealth, and strong institutions and networks—are often key indicators of resilience and adaptive capacity.

PRIORITIZE NEEDS FOR ADAPTATION

The vulnerability assessment process will inform planners and decision-makers about the projected stressors, consequent climate impacts, and multiple infrastructure systems at risk. Decision-makers can then set priorities for which infrastructure should be addressed first. Adaptation priorities can be selected through a screening process, based on decision-makers' assessment of four key factors:

- **How critical is the infrastructure to providing a needed service and ensuring lasting program effects?** Components of an infrastructure network or asset can be evaluated based on factors such as volume of use, the relative importance of different assets to daily or strategic functions, their role in emergency evacuations, and their perceived value to policy-makers.

It is especially important to consider the role infrastructure plays during disaster response when assessing criticality, since resilient infrastructure is essential to ensuring human safety and protecting lives. Infrastructure used for disaster response often represents the most critical infrastructure within each category, particularly if no backup systems exist. For example, particular aspects of the transportation network are much more critical than others. Not only are bridges connecting islands to the mainland critical in the daily transport of goods and people, they are especially important during emergencies, particularly if no alternate routes exist. In contrast, rarely used roads

in locations that have multiple access routes may be less critical. In addition, electricity generators that power hospitals and care-giving facilities are critical in providing medical attention and sustaining life.

- **How likely is the potential climate impact?** The extent of future climate change is uncertain and the pathways through which climate change will affect infrastructure are often not well understood. Therefore, it is often difficult to assign quantitative probabilities to specific climate impacts. The use of climate scenarios helps to address this challenge. These scenarios can help identify a range of potential changes and characterize the likelihood of an impact in a particular region. This information provides decision-makers with a basis for assessing the range of impacts that may occur.
- **How severe will the consequences of the climate impact be? How soon may this occur?** The severity and timing of climate impacts are important factors in identifying those that warrant the greatest attention for adaptation action. Although some weather events may have a low likelihood of occurring, the resulting damage to infrastructure and loss of life can be so severe that they still warrant adaptation measures. For example, while a 100 year flood defined as 1%-annual-chance flood in a given year may occur very infrequently, it can damage and destroy much of the area's infrastructure and endanger many lives. This type of event can be particularly damaging if disaster response infrastructure is compromised or overwhelmed. Importantly, assets used for disaster response can be affected by the same stressors for which they minor consequences in the short term (although the cumulative impacts of frequent low-consequence events may become serious over time). The anticipated timing of climate impacts is also a key consideration—imminent threats require prompt action, while impacts that are incremental or expected in future decades may allow more flexibility to adjust plans and infrastructure.
- **What resources are available?** Assuming constrained funding, technical expertise, and institutional capacity, local decision-makers need to target their resources to a subset of the highest priority needs, based on the three factors above.

DESIGN: IDENTIFY, EVALUATE, AND SELECT ADAPTATION OPTIONS



Once the vulnerability of assets is understood and priority infrastructure is identified, there is a range of actions that can be taken to improve the resilience of infrastructure. Designing adaptation actions is most effective when done as an integral part of program and project development. Illustrative examples of these adaptation actions are outlined in the fact sheets.

A range of options and strategies is available to adapt to, prepare for, and respond to the impacts of climate change. Identification of appropriate options will depend on a number of characteristics, including the impacts faced (particularly, timing and type), the location of the infrastructure asset (on coasts, highlands, river valleys, protected areas, etc.), the interconnectedness of the systems, the socio-economic context, and overall development objectives.

Other factors include the level of resources required to implement the adaptation action, as well as the system-wide impacts and benefits that will result. Some adaptation actions may require little to no resources, while others may be resource-intensive. Economic evaluation may provide helpful cost-benefit or cost-effectiveness information on adaptation options.

Alternatively, some adaptation actions may provide protection against climate change in the short-term but lead to increased vulnerability in the

medium- to long-term. Consideration of a range of future scenarios and resulting implications is important to ensuring adaptation actions sustain value into the future. Careful consideration should be paid to the resulting environmental, economic, and social impacts of actions, including the greenhouse gas emissions associated with a particular adaptation action. If thoughtfully designed, adaptation actions can not only reduce the risks of climate impacts to the infrastructure and associated services, they can also achieve important co-benefits, such as “no regrets” actions that benefit communities and support other development objectives regardless of the degree of climate change.

Adaptation actions can be classified as “hard” or “soft.” “Hard” actions involve engineered protections or structural changes to existing (or new) infrastructure, including green approaches that use natural or environmentally-focused methods, such as landscape architecture. “Soft” actions focus on policy and regulation changes, training, or educating stakeholders. Adaptation options differ in their timeframes for implementation, lifetime of use, and associated costs. A variety of feasible adaptation actions can often be identified to respond to a specific vulnerability. Examples of actions are presented in each of the fact sheets.

For infrastructure, adaptation actions can be categorized under three main approaches: accommodate and manage, protect and harden, and retreat. While not always the case, the cost of these approaches generally increases as “hard” engineering approaches or site relocation strategies are pursued.

Accommodate and Manage: These options are characterized by their focus on changes in management practices and programs. They consist of updating plans, management policies, regulations, and maintenance and operations activities. Examples include changing the frequency of repair schedules, installing redundant systems to back up a primary system in case of disruption, developing contingency plans, and providing educational and training programs. These actions often can be readily redesigned, based on an evaluation of progress, changing needs, and new information. Appropriate use of these strategies allows decision-makers to manage the level of risk and monitor conditions while deferring more costly construction or relocation approaches; in some instances no additional actions may be required. By adjusting existing practices, accommodation and management strategies can increase resilience, manage climate effects as part of routine activities, or prepare for emergency management if infrastructure does fail.

Protect and Harden: Options under this approach involve structural changes to how an infrastructure system is designed, built, renovated or protected. Protect and harden strategies include actions such as upgrading design standards (e.g., using stronger building materials) and reinforcing or fortifying existing structures (e.g., incorporating extra foundational supports, erecting protective barriers around critical roadways). Other examples of “hard” options include elevating bridges and structures, changing the curvature of drains and roads, constructing levees or sea walls, developing natural areas to provide buffer zones (such as wetlands or replenished barrier islands), and using more resilient building materials. These options can be resource-intensive in terms of the financing, technical, and organizational capacity required. Implementing these actions as part of scheduled plans for upgrades or infrastructure replacement can be most cost-effective. Further, these options tend to be more permanent, making them less able to respond to changing circumstances. In order to avoid maladaptation, long-lasting and expensive infrastructure needs to be particularly well-designed to ensure its resilience under a range of potential climate futures. When possible, designs should allow for flexibility to incorporate future changes or enhancements as warranted by evolving climate conditions (e.g., a seawall that allows for the height to be increased).

Retreat: These strategies seek to reduce the degree of exposure by relocating assets and systems away from exposed locations, such as shorelines, floodplains, and areas at risk of landslides, mudflows, floods or fire. For example, public buildings such as hospitals, disaster-related infrastructure such as evacuation routes and helipads, or other critical infrastructure systems such as power plants, water lines, or telephone sub-stations could be relocated to more protected areas (and away from coasts).

Once a subset of adaptation options has been identified, managers select a course of action. The course of action may be a set of specific actions that are “bundled” to maximize effectiveness in the context of overall development objectives. Factors such as system-wide benefits, funding constraints, stakeholder input, greenhouse gas emissions, and human resource capacity are key considerations in this process. Additionally, timing is an important factor to consider when selecting a course of action. While certain actions may require prompt implementation in order to mitigate imminent consequences, others actions may not be as urgent. If possible, implementation of capital-intensive adaptation actions should be deferred until ongoing monitoring of climate and non-climate stressors helps to reduce the uncertainty associated with the extent and magnitude of climate impacts and the effectiveness of adaptation actions.

The fact sheets provide specific examples of adaptation options for each infrastructure type. Please see USAID guidance, *Climate-Resilient Development: A Guide to Understanding and Addressing Climate Change*, for further information on how to select, integrate, and bundle adaptation strategies.

IMPLEMENT AND MANAGE: PUT ADAPTATION INTO PRACTICE



Once an individual or suite of adaptation measures is identified, managers proceed with implementing and managing this course of action.

As with traditional development programs, adaptation measures require developing and implementing a clear strategy to ensure adequate capacity, resources, awareness, and education so that these actions achieve their desired goals. This may involve a broad range of activities, including planning, policy development, and resource identification. Structural engineering projects like building adaptation structures or retrofitting facilities may take several years to design and construct. Policy-related adaptation measures may be implemented through existing programs or may require new initiatives. Building stakeholder capacity is often a key component of successful implementation and management of adaptation actions.

EVALUATE AND ADJUST: TRACK PERFORMANCE AND IMPACT



A successful adaptive management approach requires an ongoing process of monitoring and evaluation. This monitoring includes tracking the changing conditions related to the infrastructure and the efficacy of the adaptation actions taken to date. The conditions under

which infrastructure provides services are continually evolving: Climate continues to change, environmental conditions shift, populations grow, and economic and development patterns transform. Monitoring these changing conditions is critical to fully understand future challenges to the resilience of the infrastructure. Assessing the effectiveness of existing practices, as well as the adopted adaptation actions in this context helps decision-makers determine what strategies have worked, identify less effective approaches, and plan for next steps.

To understand whether implemented solutions are effective, decision-makers and planners can monitor changing climate and environmental conditions, the condition and performance of infrastructure, and changing community and regional needs.

Monitoring and evaluation are especially important because much of adaptation is proactive, seeking to address and ameliorate climate changes prior to their impacts. The data used to evaluate the likelihood, severity, and consequences of future climate changes are often relatively uncertain. Therefore, adaptation strategies and actions should be designed to respond in ways that are as robust as possible across a range of future climate conditions. The actions should be continuously monitored and evaluated to ensure that they have been implemented well, and that they are appropriate and effective as climate conditions evolve. The adaptation actions can then be adjusted on the basis of the learning that occurs through this monitoring and evaluation.

UNCERTAINTY AND CLIMATE CHANGE

Uncertainty is an inherent part of integrating climate change in infrastructure-related decisions. Sources of uncertainty include:

- Unpredictable human behavior that leads to shifting population and development patterns, change in land and resource usage, technology advances, energy consumption changes that alter emissions of greenhouse gases, governance changes, and many other factors
- Difficulty representing knowledge of physical, human, and ecological processes in models of future changes in climate and vulnerability of infrastructure and associated systems
- Inherent variability of systems, including day-to-day weather or infrastructure systems

These sources of uncertainty can be addressed in decision-making by using a wide span of climate and non-climate scenarios, by accounting for the range of current natural variability (including extremes), and by monitoring changing conditions, including the extent and magnitude of weather-related impacts on infrastructure. These characterizations of uncertainty should be discussed in any communication of modeling results to ensure that they are taken into consideration during decision-making.

NEXT STEPS

By integrating climate resilient considerations into infrastructure-supported programming, USAID and other development practitioners can ensure that programs will achieve sustainable success. This overview has provided an introduction to the basic concepts used in thinking about climate resiliency and adaptation. The accompanying infrastructure fact sheets provide more detail.

In addition to using this suite of information, development practitioners can:

Consult with specialists

Specialists can guide and support climate-resilient program and project development through the provision of technical assistance, guides, and trainings. USAID Missions can receive this information directly through Headquarters (HQ).

Refer to USAID guidance

USAID guidance, *Climate-Resilient Development: A Guide to Understanding and Addressing Climate Change*, is designed to help development practitioners understand how climate may impact their programs and projects and how these impacts can be addressed to promote climate resilient development. USAID HQ can also provide Missions with USAID-specific reference resources to help mainstream climate change into other USAID programs or design an adaptation-specific program.

Collect preliminary data

To advance the state of knowledge and begin to understand possible climate impacts, vulnerability, and risk to infrastructure, development practitioners can begin collecting data on the types and locations of infrastructure to help assess their criticality, exposure, and sensitivity. The collection of climate data for indicators such as rainfall, temperature, and extreme events is essential for assessing the historical impact of climate variability on infrastructure.

Begin assessing critical programs that are already being designed or are in place

Program staff can begin to analyze which infrastructure systems are critical to program operations and economic growth, to help prioritize actions. When designing new programs or projects, development practitioners should undertake climate risk and vulnerability assessments and consult with specialists for further guidance. Simultaneously, program/project teams should undertake assessments of existing programs and projects and understand the opportunities for mainstreaming climate considerations.

Build capacity in risk assessment and designing adaptation options

Development practitioners can attend adaptation and adaptive management trainings that will guide them through conducting risk and vulnerability assessments and appropriate management strategies. Information is also available through the various climate change-related knowledge portals and online trainings. USAID HQ can provide Mission staff with USAID-specific trainings, guidance, and reference documents.

Begin to integrate measures to address infrastructure climate risk into projects

After assessment activities and training, development practitioners should begin to mainstream climate risk considerations into projects and programs by designing redundancy plans, considering changes in management and operations, and providing guidance to stakeholders on better practices and lessons learned.

ADDITIONAL RESOURCES

Adapting to Climate Variability and Change: A guidance manual for development planning

http://pdf.usaid.gov/pdf_docs/PNADJ990.pdf

Climate One-Stop

<http://arcserver4.iagt.org/climate1stop/Default.aspx?mode=modeDataVisualization>

SERVIR

<http://www.servir.net/>

Climate Change Knowledge Portal

<http://sdwebx.worldbank.org/climateportal/index.cfm>

Climate Wizard

<http://www.climatewizard.org/index.html>

Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability

http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries

<http://unfccc.int/resource/docs/publications/impacts.pdf>

National Communications

http://unfccc.int/national_reports/non-annex_i_natcom/items/2979.php

National Adaptation Programme of Action (NAPA)

http://unfccc.int/cooperation_support/least_developed_countries_portal/submitted_napas/items/4585.php

Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors (AIACC)

<http://sedac.ciesin.columbia.edu/aiacc/>

Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)

http://www.ipcc-wg2.gov/SREX/images/uploads/SREX-SPMbrochure_FINAL.pdf



TRANSPORTATION

ADDRESSING CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE: PREPARING FOR CHANGE

Washed-out bridge. Photo Credit: IRG



- ▶ Climate change impacts on transportation infrastructure may include temporary or permanent flooding of roads, bridges, and ports; increased maintenance costs due to damage or increased wear and tear; and service disruption.
- ▶ Since reliable transportation is essential to strong communities and economic development, climate change impacts on transportation infrastructure could have far-reaching implications for development programs, especially those that rely on transportation to gain access to the populations they serve.
- ▶ Transportation-related adaptation options include designing back-up services, constructing storm surge barriers, and elevating roadways. In some instances, infrastructure may need to be relocated.

TRANSPORTATION IS INTEGRAL TO DEVELOPMENT PRIORITIES

Transportation infrastructure often forms the critical backbone of local, regional, national, and international economic and community activities. It enables the distribution of goods and services within and between countries and eases access to schools, markets, and health services. As such, transportation infrastructure is critical to development programs around the world.

In order to implement food security programs, for example, USAID and other development practitioners have to support the development and operation of roads and rails, as well as access to ports and airports, to allow the movement of critical food supplies to and from markets. **By supporting reliable and climate-resilient transportation, USAID and other development practitioners can ensure lasting program effects.**

CLIMATE STRESSORS CAN SIGNIFICANTLY IMPACT TRANSPORTATION SYSTEMS

Changes in the variability and magnitude of temperature, precipitation, rising sea levels, and extreme weather events can affect transportation infrastructure. For example, rising sea levels can permanently inundate coastal transportation networks, rendering roads, airports, and ports unusable; increased storm surge due to rising sea levels and more intense

TRANSPORTATION INCLUDES:

- Roads (including bridges, tunnels, and bicycle/ pedestrian paths)
- Railways
- Ports and waterways
- Airports

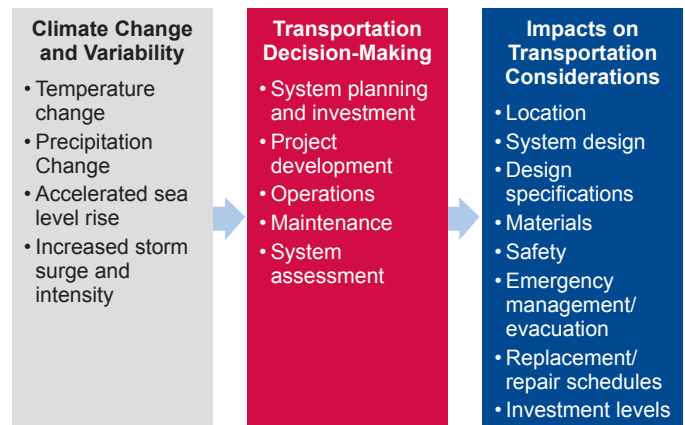
TRANSPORTATION SUPPORTS:

- Food security programs
- Humanitarian assistance
- Urban programs
- Economic growth and trade

storms can significantly damage infrastructure; and areas that endure prolonged high temperatures may experience road deterioration or rail buckling that can disrupt transportation and trade routes. These impacts affect access to markets, schools, and health centers.

Climate change risks vary in relative importance, with a range of cost implications, compounding effects, and impacts on development objectives. Figure 1 provides further information on how climate change and variability can affect transportation decision-making and what factors may have to be considered. Please see Table 1 for additional examples of climate change impacts on transportation, many of which are already being experienced.

Figure 1. Climate Change Impacts Can Affect a Range of Transportation-Related Decisions¹



¹ Figure adapted from CCSP, 2008. Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I. Savonis, M.J., V.R. Burkett, and J.R. Potter (eds). Department of Transportation, Washington, D.C.

Table I. Examples of Potential Climate Change Impacts on Transportation Infrastructure and Services

	Roads	Railways	Ports and Waterways	Airports
Temperature Change	<ul style="list-style-type: none"> • More rapid road asphalt deterioration due to prolonged heat • Substructure damage and buckling due to permafrost thaw • Increased maintenance and construction costs 	<ul style="list-style-type: none"> • Expansion and buckling of railway tracks, joints • Overheating of rail electrical systems and communications equipment 	<ul style="list-style-type: none"> • Thermal expansion of bridge joints, paved surfaces • Higher land-side electricity consumption to meet increased refrigeration needs 	<ul style="list-style-type: none"> • Asphalt deterioration on runways • Length of runways inadequate due to decreasing air density
Precipitation Change	<ul style="list-style-type: none"> • Increased flooding of roadways • Increased soil erosion and washout of road- and tunnel-supporting culverts during flash floods 	<ul style="list-style-type: none"> • Increased flooding of tracks and stations • Washout of track supports (ballast) 	<ul style="list-style-type: none"> • Changes in scour rates in response to increased peak stream flow • Channel closures due to increased silt deposition from flooding • Reduced navigability due to low water levels 	<ul style="list-style-type: none"> • Travel disruptions due to storms and runway closures due to flooding • Damage to airport infrastructure due to inundation
Sea Level Rise	<ul style="list-style-type: none"> • Erosion of roadbase 	<ul style="list-style-type: none"> • Flooding of underground pathways and tunnels 	<ul style="list-style-type: none"> • Diminished access due to rising sea levels 	<ul style="list-style-type: none"> • Erosion of coastal airport runways
	<ul style="list-style-type: none"> • Permanent inundation of road, rail, port, and airport infrastructure 			
Storm Surge	<ul style="list-style-type: none"> • Temporary inundation of and diminished access to roadways, rails, ports, and airport facilities • Closure of facilities due to debris (e.g., cranes) and damage to infrastructure (e.g., clogging of drainage systems) 			

DEVELOPMENT ORGANIZATIONS CAN MAINSTREAM TRANSPORTATION-RELATED ADAPTATION INTO THEIR PROGRAMS






Many options exist to adjust to or cope with the projected impacts of climate change. Despite limited resources, development practitioners and local decision-makers can use a screening process to select adaptation priorities based on their assessment of four key factors.

- **Criticality** – How important is the transportation infrastructure to the community or region? Is it required for emergency response? Are redundant services available?
- **Likelihood** – Given climate projections, is the road, bridge, port, or airport (i.e., the component in question) likely to be impacted by climate change? When are these impacts expected?
- **Consequences** – How significant is the impact? Will climate changes permanently or temporarily disrupt services?
- **Resources available** – Are both organizational capacity and financial and technical resources available to implement adaptation? Can adaptation options be integrated into existing maintenance schedules or do components have to be replaced in whole?

Adaptation priorities should be mainstreamed into existing capital improvement and maintenance programs, where possible. Adaptation options range from “hard” options (e.g., elevating bridges, changing asphalt composition) to “soft” options (e.g., increasing maintenance activities, changing land zoning practices, providing incentives for inland construction) and require differing levels of resources, depending on when they are incorporated into design and planning. Table 2 provides examples of the range of transportation-related adaptation options that may be considered.

By intentionally integrating climate information into program development and investment decisions, USAID and other development practitioners can avoid maladaptive projects such as investing in a bridge repair that is likely to be inundated by rising sea levels. While an ad-hoc approach to transportation development may result in positive short-term effects, an integrated, climate-resilient approach will maintain value in the longer term. Table 2 illustrates this approach, aligned with the Climate-Resilient Development (CRD) Framework. See the Overview for further guidance on the CRD Framework.

Table 2. Examples of Transportation-Related Actions by Project Cycle Stage

Project Cycle Stage	Project Cycle Actions		
	<ul style="list-style-type: none"> Identify transportation-related development goals important to the country, community, or sector you are working with Identify inputs and enabling conditions necessary to achieving those goals Consider the impacts of climate and non-climate stressors on those inputs 		
	<ul style="list-style-type: none"> Assess potential climate impacts on transportation infrastructure to understand adaptation needs and economic implications Evaluate climate-related risks in light of all existing risks to transportation 		
 Planning Policy Changes Project Development	Adaptation Options (Examples)		
	ACCOMMODATE/MANAGE <ul style="list-style-type: none"> Develop redundant services to accommodate disruptions Shorten maintenance periods to accommodate changes in temperature and precipitation Plan for extreme event evacuation 	PROTECT/HARDEN <ul style="list-style-type: none"> Update design standards to elevate roadways to accommodate future sea level rise and high winds Consider storm surge in coastal road planning 	RETREAT/RELOCATE <ul style="list-style-type: none"> Plan for coastal roadway relocation Convert coastal land uses to establish natural buffer zones
 Construction Operation Maintenance Program Activities	Adaptation Options (Examples)		
	ACCOMMODATE/MANAGE <ul style="list-style-type: none"> Increase financial and technical resources for more frequent maintenance and repairs Temporarily close airports and ports due to extreme weather 	PROTECT/HARDEN <ul style="list-style-type: none"> Update design standards to elevate Use flexible, expandable materials in railway systems Use improved asphalt/ concrete mixtures for roads and runways 	RETREAT/RELOCATE <ul style="list-style-type: none"> Relocate roads, railways, and airport runways further inland
	<ul style="list-style-type: none"> Track changes in maintenance needs and schedules over time as adaptation actions are implemented Monitor changing environmental conditions affected by climate (e.g., land erosion patterns, frequency and severity of inundation events) to understand evolving adaptation needs 		

FURTHER READING

Transportation Research Board, 2008. Potential Impacts of Climate Change on U.S. Transportation. <http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf>

U.S. Climate Change Science Program, 2008. Synthesis and Assessment Product 4.7: Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I. <http://www.climatechange.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf>



POTABLE WATER SYSTEMS

ADDRESSING CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE:
PREPARING FOR CHANGE

Water pump in Iloilo, Philippines. Photo Credit: Jessica Troell



- ▶ Climate change may reduce availability of reliable water, due to droughts, degradation of water quality, and disruption in service.
- ▶ Since safe potable water is essential to the economic and physical health of a community, climate change impacts on potable water supplies will have wide-reaching implications for development projects and programs.
- ▶ Adaptation options such as improving water capture and storage, spreading and implementing best practices in water conservation, and protecting water quality, reduce climate change risks.

POTABLE WATER SYSTEMS ARE INTEGRAL TO DEVELOPMENT PRIORITIES

Potable safe drinking water is crucial to a community's economic and physical health. Water-related diseases are the most common cause of illness and death among the poor in developing countries. Unsafe drinking water, inadequate sanitation, and poor hygiene cause nearly two million deaths due to diarrhea each year, with children under the age of five accounting for the vast majority of these deaths. Providing potable water goes hand-in-hand with improving sanitation and hygienic practices to protect public health.

Recognizing that potable water is an essential requirement for development, USAID and other development practitioners are already actively supporting potable water projects throughout the developing world. **Accounting for climate change in water project design and implementation will ensure that investments provide effective, long-term, and sustainable solutions.**

CLIMATE STRESSORS CAN SIGNIFICANTLY IMPACT POTABLE WATER SYSTEMS

Climatic patterns greatly influence both water supply and quality. Climate change can affect the availability of water supplies by increasing the severity of short- and long-term droughts, the melting of glaciers, and the intensity of storms. Rising sea levels and storm surges can cause salt water intrusion leading to the salinization of fresh water supplies. Rising temperatures can increase water demand for drinking, irrigation, and green spaces, while also causing greater evaporation from reservoirs. These effects can all necessitate additional water storage. Competing

POTABLE WATER SYSTEMS INCLUDE:

- Water supply systems
- Water treatment systems
- Water storage and distribution infrastructure

POTABLE WATER SYSTEMS SUPPORT:

- Health
- Food security
- Economic productivity
- Tourism

priorities for water (e.g., drinking water, hydropower, and agriculture) can further exacerbate reduced availability and increased costs of potable water.

Climate change can also affect water quality. More intense storms can lead to increased sediment and pathogen loading. Increased temperatures may degrade water quality by promoting algal blooms, increasing pathogen concentrations, and lowering dissolved oxygen levels. In cities, the "urban heat island effect" can intensify temperature increases, exacerbating water quality issues. Changes in water quality could require significant investment in improved source water protection, water treatment, or development of new sources of water.

Impacts that lead to decreasing water supply and quality may have far-reaching impacts on public health, economic growth, and other development goals. Table 1 on the next page provides examples of how climate stressors may impact water supply, treatment, and storage and distribution. These risks vary in relative importance, with a range of cost implications, compounding effects, and impacts on development objectives.

POTABLE WATER-RELATED ADAPTATION CAN BE MAINSTREAMED INTO EXISTING PROGRAMS

Climate changes will require the adaptation of potable water systems. To ensure a reliable and sustainable supply of safe potable water, the development community should consider climate change impacts and

Table 1. Examples of Potential Climate Change Impacts on Potable Water Infrastructure and Services

	Water Supply	Water Treatment	Water Storage and Distribution
Temperature Increase	<ul style="list-style-type: none"> • Reduced capacity of existing infrastructure (pumps, pipes, storage, and treatment facilities) to meet increased demands • Decreased water quality increasing likelihood that existing treatment infrastructure is inadequate 	<ul style="list-style-type: none"> • Increased water treatment requirements and costs to address lower water quality (e.g., increased algal blooms and bacterial and fungal content) 	<ul style="list-style-type: none"> • Increased storage capacity requirements due to increased demand • Increased water losses during storage • Decreases in water quality during storage and distribution
Increased Intensity of Precipitation and Storm Events	<ul style="list-style-type: none"> • Increased turbidity loading in reservoirs, due to greater runoff • Less groundwater recharge due to faster runoff • Damage to or inundation of infrastructure 	<ul style="list-style-type: none"> • Lower treatment efficiency due to rapidly changing water quality • Inundation of treatment facilities during storm events • Loss of power disrupting treatment operations • Damage to water treatment facilities and distribution networks 	<ul style="list-style-type: none"> • Additional storage facilities needed to capture water during short, high intensity storm events • Greater need to ensure distribution system integrity, to minimize inflow of contaminated waters during storm events • Damage to storage facilities and distribution systems from increased runoff • Increased contamination of wells from contaminated runoff
Prolonged Drought	<ul style="list-style-type: none"> • Need for additional sources of water; and associated conveyance, storage, and treatment infrastructure, to respond to short- and long-term droughts 	<ul style="list-style-type: none"> • Increased water treatment costs and requirements to address lower water quality (e.g., higher pollutant concentrations due to reduced dilution) 	<ul style="list-style-type: none"> • Need for additional water storage to address drought periods • Need to reduce water losses, and implement water conservation • Need for deeper wells to reach lower water tables • Increased cost and energy requirements to distribute water from new sources
Sea Level Rise	<ul style="list-style-type: none"> • Saltwater intrusion of freshwater supplies • Corrosion of water conveyance infrastructure 	<ul style="list-style-type: none"> • Inundation of low-lying treatment facilities and wells 	<ul style="list-style-type: none"> • Need for additional water storage to replace wells impacted by saltwater intrusion

adaptation in existing programs and projects. Adaptation may involve additional investment, improved operation and maintenance, and long-term planning. To maximize the impact of investments, decision-makers need to consider four key factors when prioritizing adaptation efforts. These include:






- **Criticality** – How important is the potable water infrastructure to achieving development objectives in a particular region?
- **Likelihood** – What is the probability of the climate impact occurring and affecting the infrastructure?
- **Consequences** – Will the climate impact temporarily or permanently decommission the use of the potable water infrastructure? Will the impact reduce water availability below a critical threshold?
- **Resources available** – What financial and technical resources are available to integrate adaptation options into program activities?

As shown in Table 2, there is a range of adaptation options to increase the availability of water, to ensure water quality, and to protect and harden

water treatment facilities. Both hard and soft responses exist. “Hard” options refer to structural changes such as constructing reservoirs, holding ponds, rainwater harvesting systems, and water treatment facilities. “Soft” options refer to management, operational, or policy changes such as changes in maintenance activities, changes in land protection or zoning practices to protect water quality, and training and education for water conservation.

By intentionally integrating climate information into program development and investment decisions, USAID and other development practitioners can avoid maladaptive projects, such as constructing a new well in an area where sea level rise will cause saltwater intrusion of groundwater thus rendering the well unusable, or building a new water treatment facility in a location that may be susceptible to flooding from extreme precipitation events (or in a location that will not yield sufficient water, given future extended dry periods). While an ad-hoc approach to potable water development may result in positive short-term effects, an integrated, climate-resistant approach will maintain value over the long term. Table 2 illustrates this approach, aligned with the Climate-Resilient Development (CRD) Framework. See the Overview for further guidance on the CRD Framework.

Table 2. Examples of Potable Water-Related Actions by Project Cycle Stage

Project Cycle Stage	Project Cycle Actions		
	<ul style="list-style-type: none"> Identify water-related development goals important to the country, community, or sector you are working with Identify inputs and enabling conditions necessary to achieving those goals Consider the impacts of climate and non-climate stressors on those inputs 		
	<ul style="list-style-type: none"> Assess climate impacts on water quality and the need for additional water treatment or other management options Assess climate impacts on water availability and the need for additional storage, water conservation, etc. 		
 <p>Planning Policy Changes Project Development</p>	Adaptation Options (Examples)		
	<p>INCREASE AVAILABILITY</p> <ul style="list-style-type: none"> Develop redundant services to Increase water capture and storage options Develop projects to reduce water losses Evaluate new sources of water including reclaimed water Develop policies to limit the use of potable water and increase the use of recycled water for irrigation Develop water conservation programs 	<p>ENSURE WATER QUALITY</p> <ul style="list-style-type: none"> Develop a source water protection strategy Investigate land use and waste management policies to improve source water quality Develop a coastal aquifer protection strategy Evaluate treatment options to improve water quality 	<p>PROTECT/HARDEN/RETREAT</p> <ul style="list-style-type: none"> Plan back-up power systems for water treatment and pumping facilities Evaluate options to relocate water treatment infrastructure Improve distribution system infrastructure
 <p>Construction Operation Maintenance Program Activities</p>	Adaptation Options (Examples)		
	<p>INCREASE AVAILABILITY</p> <ul style="list-style-type: none"> Install new or improved water storage options Implement training and education programs to promote water conservation 	<p>ENSURE WATER QUALITY</p> <ul style="list-style-type: none"> Implement programs to protect source water quality Work with local governments to implement land use practices and waste management policies to improve water quality Build and operate upgraded water treatment facilities 	<p>PROTECT/HARDEN/RETREAT</p> <ul style="list-style-type: none"> Relocate at-risk facilities out of flood-prone areas Provide back-up power sources
	<ul style="list-style-type: none"> Track performance of water systems and the availability of water during short-term events and over time Monitor changing environmental conditions affected by climate and their impact on water supply and treatment 		

FURTHER READING

U.S. Agency for International Development, 2012. Drinking Water, Sanitation and Hygiene. http://transition.usaid.gov/our_work/cross-cutting_programs/water/water_sanitation.html



SANITATION SYSTEMS

ADDRESSING CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE: PREPARING FOR CHANGE

Newly constructed latrines at a camp for internally displaced persons in Liberia.
Photo Credit: USAID/OFDA



- ▶ Many sanitation facilities are located at the lowest elevation possible and are therefore vulnerable to climate change-related sea level rise, storm surge, and flooding. More severe storm events can overwhelm facilities. Lower stream levels and higher temperatures can affect water quality.
- ▶ Climate change impacts on sanitation systems could have negative health implications as well as damaging ecosystems.
- ▶ Relocating facilities to higher elevations, separating storm and wastewater sewers, and improving treatment to produce a higher quality effluent can help mitigate climate risks.

SANITATION SYSTEMS ARE INTEGRAL TO DEVELOPMENT PRIORITIES

Basic sanitation is crucial to the overall health of communities, as well as the environment. So, sanitation initiatives, often in conjunction with hygiene projects, are frequently high priority programs for development organizations. Water-related diseases are the most common cause of illness and death among the poor in developing countries. Estimates indicate that more than two billion people live without access to adequate sanitation. Unsafe drinking water, inadequate sanitation, and poor hygiene cause nearly two million deaths each year; children under the age of five account for the vast majority of these deaths.

Lack of sanitation can hinder other development priorities such as improved global health, economic productivity, and food security. Water, Sanitation, and Hygiene (WASH) programs seek to increase access to the drinking water supply or sanitation services, improve the quality of those services, and/or promote hygiene. Some water and sanitation programs offer opportunities to help people adapt to climate variability and change. But when climate is not considered, the objectives of other programs may well be undermined. **As a result, supporting climate change adaptations for sanitation systems will increase the resilience of development programs to improve public health and environmental protection.**

SANITATION SYSTEMS INCLUDE:

- Latrines
- Septic and leach field systems
- Wastewater treatment infrastructure

SANITATION SYSTEMS SUPPORT:

- Health
- Economic productivity
- Environmental protection and ecosystem health
- Tourism
- Food and water security

CLIMATE STRESSORS CAN SIGNIFICANTLY IMPACT SANITATION SYSTEMS

Sanitation facilities are highly sensitive to storm surge, sea level rise, and flooding. Wastewater collection and treatment facilities are often situated at the lowest point possible as their operation leverages gravitational pull, but they can therefore easily be inundated by water level rise. When storm water and sewer collection systems are combined, higher intensity storms can overwhelm treatment facilities leading to a failure of treatment. Septic systems and leach fields need to be separated from the water table for effective treatment but rising groundwater levels during flooding or rising sea levels will limit their effectiveness. **Rising water levels due to storm surge, sea level rise, and flooding can lead to a failure of sanitation systems, impacting community health.**

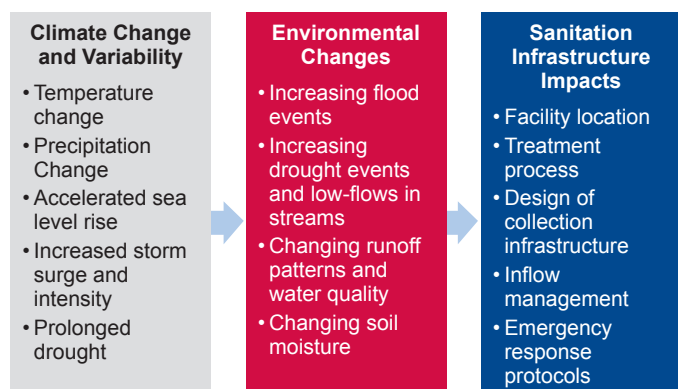
Lower stream flows during both short- and long-term drought periods can limit the effectiveness of receiving water bodies to absorb and dilute pollution coming from sanitation facilities. In addition, higher temperatures can cause more frequent algal blooms and increase bacterial and fungal content in water. In cities, the “urban heat island effect” can intensify temperature increases, exacerbating water quality issues. These effects lead to eutrophication, increased pathogen loading, and lower dissolved oxygen levels. The resulting decreased ability to absorb and dilute pollution will require improved sanitation systems to protect the public health and environment of downstream communities.

Table I. Examples of Potential Climate Change Impacts on Sanitation Infrastructure and Services

	Wastewater Treatment	Latrines	Septic and Leach Field
Temperature Increase	<ul style="list-style-type: none"> Lower water quality due to increased algal blooms and pathogens, and lower dissolved oxygen 	<ul style="list-style-type: none"> Increased odors making use less attractive 	Minimal impact
Increased Intensity of Precipitation and Storm Events	<ul style="list-style-type: none"> Overwhelmed treatment systems, especially associated with combined sewers or through inflow/infiltration Inundation of outfall causing discharge to back up Flood damage to collection systems and treatment facilities Disruptions of pumping and treatment due to power loss 	<ul style="list-style-type: none"> Decreased separation from groundwater due to rising water tables Inundation and overflow of latrines 	<ul style="list-style-type: none"> Decreased separation from groundwater due to rising water tables
Prolonged Drought	<ul style="list-style-type: none"> Reduced capacity of water resources to absorb and dilute pollution due to lower flows in receiving streams Reduced treatment performance due to lower flows 	Minimal Impact	Minimal Impact
Sea Level Rise	<ul style="list-style-type: none"> Inundation of low-lying treatment facilities requiring relocations Inundation of outfall causing discharge to back-up 	<ul style="list-style-type: none"> Inundation of low-lying latrines requiring relocation Decreased effectiveness due to rising water tables 	<ul style="list-style-type: none"> Inundation of low-lying septic systems requiring relocation Decreased effectiveness due to rising water tables

Figure 1 provides further information on how climate change and variability can affect sanitation-related decision-making and details factors to be considered. Table I on the next page provides examples of potential climate change impacts on sanitation infrastructure and services. Climate change risks vary in relative magnitude and importance, with a range of cost implications, compounding effects, and impacts on development objectives. For example, dry and low-flush pit latrines have relatively high resilience to climate change impacts due to lower sensitivity and significant adaptive capacity through changes in design.

Figure 1. Climate Change Impacts Can Affect a Range of Sanitation-Related Decisions



MAINSTREAMING SANITATION-RELATED ADAPTATION INTO EXISTING PROGRAMS

USAID, other development organizations, and local decision-makers can identify appropriate adaptation action priorities and integrate them into existing capital improvement and maintenance programs. Where






appropriate, collection, processing, and disposal systems may have to be relocated or re-routed. For example, septic tank systems situated in coastal areas would have to be strengthened or relocated to prevent inundation and contamination of ground water due to rising sea levels. Response strategies can be designed and prioritized based on decision-makers' assessment of the following factors:

- **Criticality** – How important is the sanitation infrastructure to the community or region? Are backup services available?
- **Likelihood** – Given climate scenarios, what is the probability that sanitation systems will be affected?
- **Consequences** – How significant is the impact? Will climate changes permanently or temporarily disrupt sanitation services?
- **Resources available** – Can changes be made with only modest cost increases to already-occurring replacement? Does sanitation infrastructure have to be replaced or relocated prematurely?

Adaptation options can range from hard to soft responses. "Hard" options refer to structural changes (e.g., moving septic tanks and associated pipelines to higher ground). "Soft" options refer to management, operational, and policy changes (e.g., increasing maintenance of tanks and pipes, maintaining backup systems.) See Table 2 for a list of sanitation-related adaptation options that fit within the Climate-Resilient Development (CRD) Framework and the Overview for further guidance.

Some adaptation strategies may require little or no additional funding, if climate factors are incorporated into upfront planning and design. Other strategies may require significant additional resources. By intentionally integrating climate information into program development and investment decisions, development practitioners can avoid maladaptive projects such as constructing septic tanks in low-lying areas or flood plains and combining storm and sanitary sewers. **Mainstreaming climate considerations into careful planning processes will ensure that sanitation programs maintain their value in the long-term.**

Table 2. Examples of Sanitation-Related Adaptation Options by Project Cycle Stage

Project Cycle Stage	Project Cycle Actions				
	<ul style="list-style-type: none"> Identify sanitation-related development goals important to the country, community, or sector you are working with Identify inputs and enabling conditions necessary to achieving those goals Consider the impacts of climate and non-climate stressors on those inputs 				
	<ul style="list-style-type: none"> Assess climate impacts on sanitation systems Assess climate impacts on human health from reduced water quality associated with pollutant discharge 				
Adaptation Options (Examples)					
 <p>Planning Policy Changes Project Development</p>	<table border="1"> <thead> <tr> <th>SANITARY INFRASTRUCTURE</th> <th>WATER QUALITY</th> </tr> </thead> <tbody> <tr> <td> <ul style="list-style-type: none"> Evaluate improving, elevating, or moving treatment facilities to prevent overflows and inundation Plan back-up power systems for treatment and pumping facilities Site septic and leach field systems at higher elevations Develop plans for reclaimed water systems </td> <td> <ul style="list-style-type: none"> Develop a source water protection plan that accounts for the impacts of low flow on the ability of natural systems to dilute and absorb pollutants </td> </tr> </tbody> </table>	SANITARY INFRASTRUCTURE	WATER QUALITY	<ul style="list-style-type: none"> Evaluate improving, elevating, or moving treatment facilities to prevent overflows and inundation Plan back-up power systems for treatment and pumping facilities Site septic and leach field systems at higher elevations Develop plans for reclaimed water systems 	<ul style="list-style-type: none"> Develop a source water protection plan that accounts for the impacts of low flow on the ability of natural systems to dilute and absorb pollutants
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Adaptation Options (Examples)					
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SANITARY INFRASTRUCTURE	WATER QUALITY				
<ul style="list-style-type: none"> Move existing facilities or site new facilities on higher ground to account for flooding or sea water rise Separate storm water and sewage collection systems Implement programs to reduce inflow and infiltration Integrate information on climate change impacts into training and education about sanitation systems Clean latrine systems more regularly to prevent overflows 	<ul style="list-style-type: none"> Construct new or improve existing treatment facilities 				
	<ul style="list-style-type: none"> Track performance of inflow and infiltration reduction programs Monitor water discharges for changes in effluent characteristics Monitor water quality levels and evaluate need for new or modified source water protection plans 				

FURTHER READING

ICLEI, 2011. Adapting Urban Water Systems to Climate Change: A handbook for decision makers at the local level. http://iwahq.org/ContentSuite/upload/iwa/all/Water%20climate%20and%20energy/SWITCH_Adaption-Handbook_final_small.pdf

WHO, 2010. Guidance on Water Supply and Sanitation in Extreme Weather Events. http://www.wsscc.org/sites/default/files/publications/who_guidanceextremeweathereventswash_2010-eng.pdf

WHO, 2010. Vision 2030: The Resilience of Water Supply and Sanitation in the face of Climate Change. http://www.who.int/water_sanitation_health/publications/vision_2030_technical_report.pdf



SOLID WASTE MANAGEMENT

ADDRESSING CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE: PREPARING FOR CHANGE

Leachate running from a break in a landfill wall following a major storm. Photo Credit: Joe Teixeira, 2011



- ▶ Climate change impacts on solid waste management infrastructure and surrounding environment may be temporary or long-lasting.
- ▶ Poor management of solid waste can lead to rodent infestations, disease outbreak, and groundwater contamination.
- ▶ Solid waste-related adaptation options include protecting critical infrastructure, reducing facility needs through recycling and demand management, and requiring waste treatment facilities to prepare adaptation plans.

SOLID WASTE MANAGEMENT IS INTEGRAL TO DEVELOPMENT PRIORITIES

Solid waste collection, processing, and disposal is critical to development practitioners' environment and health sector priorities, including maintaining clean air, soil, and water; particularly in urban settings. Moreover, most solid waste management helps mitigate greenhouse gas emissions.

Trash collection is important for maintaining sanitary conditions, particularly in residential and business areas where food debris can attract rodents and insects while decaying organic matter can cause unpleasant odors. Once collected, solid waste must be separated and managed by type such as municipal waste; commercial, industrial, and construction waste; agricultural waste; and medical and hazardous waste. Medical and hazardous waste should be treated and/or contained so that it does not contaminate people, ground and surface water, soil, or air. Municipal waste should be sorted to remove reusable or recyclable material and stored in a landfill designed to contain waste and manage decomposition.

While many areas around the world do not yet have established waste management systems, it is critical that all new and existing solid waste management systems be designed and maintained to be resilient to climate change. **By supporting programs to reduce waste, increase collection, and build and maintain climate-resilient disposal sites, USAID and other development practitioners can contribute to health and resource management objectives that promote lasting program benefits.**

SOLID WASTE MANAGEMENT INCLUDES:

- Collection
- Processing, treatment, and recycling
- Disposal

SOLID WASTE MANAGEMENT SUPPORTS:

- Urban programs
- Health programs
- Environmental management

CLIMATE STRESSORS CAN SIGNIFICANTLY IMPACT SOLID WASTE MANAGEMENT SERVICES

Climate stressors can impact solid waste facilities both directly and indirectly. For example, while higher temperatures may directly alter decomposition rates, climate change may also affect access to roads, ports, and energy, indirectly limiting the collection of waste and operation of waste management sites.

Flooding poses the biggest threat to solid waste infrastructure. Without proper water catchment systems around a landfill, heavy rain events can degrade the landfill, causing breaks in the containment structure that allow debris and leachate to escape from the landfill and contaminate local resources. Flooding from extreme storms may undermine landfill foundations, releasing leachate into groundwater or block collection routes, sweep waste into waterways, and cause waste to clog other infrastructure. Landfills near the coast or in low-lying areas are vulnerable to sea level rise and storm surge. Water infiltration of the pit can lead to an overflow of waste from the landfill. Saltwater infiltration from below can deteriorate the impermeable lining of sanitary landfill facilities.

Temperature increases may necessitate more frequent waste collection schedules and rigorous landfill management practices, as odors will be stronger. Higher temperatures and drought may also increase the risks of fire at waste facilities.

These and other climate change risks vary in relative importance, with a range of cost implications, compounding effects, and impacts on development objectives. Please see Table 1 on the next page for additional examples.

Table I. Examples of Potential Climate Change Impacts on Solid Waste Management Infrastructure and Services

	Collection	Processing	Disposal
Temperature Change	<ul style="list-style-type: none"> Increased odor and pest activity requiring more frequent waste collection Overheating of collection vehicles requiring additional cooling capacity, including to extend engine life 	<ul style="list-style-type: none"> Overheating of sorting equipment 	<ul style="list-style-type: none"> Altered decomposition rates Increased maintenance and construction costs due to thawing permafrost Increased risk of fire at disposal sites
	<ul style="list-style-type: none"> Greater exposure of workers to flies, which are a major cause of infectious diseases (flies breed more quickly in warm temperatures and are attracted to organic waste) 		
Precipitation Change	<ul style="list-style-type: none"> Flooding of collection routes and landfill access roads, making them inaccessible Increased stress on collection vehicles and workers from waterlogged waste 	<ul style="list-style-type: none"> Increased need for enclosed or covered sorting facilities 	<ul style="list-style-type: none"> Increased flooding in/around sites Increased leachate that needs to be collected and treated Potential risk of fire if conditions become too dry and hot
Sea Level Rise	<ul style="list-style-type: none"> Narrowed collection routes Potentially increased waste in a concentrated area as people crowd into higher elevations within an urban area 	<ul style="list-style-type: none"> Damage to low-lying processing facilities Increased need for sorting and recycling to minimize waste storage needs 	<ul style="list-style-type: none"> Deterioration of impermeable lining Water infiltration of pit leading to possible overflow of waste
	<ul style="list-style-type: none"> Permanent inundation of collection, processing, and disposal infrastructure 		
Storm Surge	<ul style="list-style-type: none"> Temporary flooding of and diminished access to roadways, rails, and ports for waste collection, sorting, and disposal Closure of facilities due to infrastructure damage 		
Extreme Wind	<ul style="list-style-type: none"> Dispersal of waste from collection sites, collection vehicles, processing sites, and landfills Reduced access to collection and landfill access routes due to damage and debris 		

SOLID WASTE MANAGEMENT-RELATED ADAPTATION CAN BE MAINSTREAMED INTO EXISTING PROGRAMS

USAID and other development practitioners can identify adaptation action priorities and integrate them into existing improvement and maintenance programs. Waste collection and disposal facilities are critical to protecting human health and local resources (particularly water and soil resources). Regular collection, particularly in residential areas, reduces exposure to contaminated waste and disease-carrying rodents and insects. Properly sited, constructed, and maintained disposal facilities can minimize the risk of water and soil contamination from the consequences of climate change impacts.

Reducing the amount of solid waste stored in landfills is one of the easiest ways to reduce their vulnerability. Establishing waste sorting and recycling facilities can create local jobs and perhaps provide work for trash pickers whose livelihoods were compromised by a more robust municipal waste collection system. Recycling also reduces resource use and the amount of waste that must be managed in a landfill.






Proper siting of landfills is another low-cost adaptation option. Landfills should be sited in areas where there is reliable access to the dumping site but away from bodies of water and areas with high water tables. Sites should be selected based on the municipality's long-term planning objectives and include input from the public.

Through a screening process, adaptation action priorities can be selected based on local decision-makers' assessment of the following four key factors (presented with illustrative questions). Please see the Overview for more information.

- **Criticality** – How important is the infrastructure to the community or region? How large is the population served by the waste management system? Are backup services available?
- **Likelihood** – Given climate projections, what is the probability that the collection, processing, or disposal infrastructure will be affected?
- **Consequences** – How significant is the impact? Will the impacts complicate solid waste management? Will the impacts have health implications?
- **Resources available** – Can changes be made to collection, processing, or disposal using a reallocation of existing time and resources? Are additional resources, such as additional workers, required?

By understanding the answers to these questions, adaptation actions (like those listed in Table 2) can be integrated into the upfront design, construction, operation, and maintenance of solid waste management systems. Integrating adaptation can prevent maladaptive decisions that increase the vulnerability of the infrastructure and people they are trying to serve. Table 2 illustrates this approach, aligned with the Climate-Resilient Development (CRD) Framework. See the Overview for further guidance on the CRD Framework.

Table 2. Examples of Solid Waste Management-Related Actions by Project Cycle Stage

Project Cycle Stage	Project Cycle Actions		
	<ul style="list-style-type: none"> Identify solid waste-related development goals important to the country, community, or sector you are working with Identify inputs and enabling conditions necessary to achieving those goals Consider the impacts of climate and non-climate stressors on those inputs 		
	<ul style="list-style-type: none"> Assess climate threats, vulnerabilities, and impacts to solid waste collection, processing, and storage to understand adaptation needs Evaluate climate-related risks in light of all existing risks to solid waste 		
 <p>Planning Policy Changes Project Development</p>	Adaptation Options (Examples)		
	ACCOMMODATE/MANAGE <ul style="list-style-type: none"> Properly site landfills away from floodplains, wetlands, or areas with high water tables Site landfills away from drinking water supplies Develop sites large enough to accommodate projected population growth and corresponding waste generation Design sites with sorting, recycling, and composting facilities to reduce waste storage needs 	PROTECT/HARDEN <ul style="list-style-type: none"> Update design standards to elevate and strengthen containment walls to accommodate future sea level rise and high winds Design water catchment systems that can keep pace with projected rainfall patterns Update equipment design standards to increase efficiency and reduce maintenance costs in changing climate, particularly for complex, HVAC-dependent equipment 	RETREAT/RELOCATE <ul style="list-style-type: none"> Plan for secure landfill closure and/or relocation Plan for extreme event evacuation
 <p>Construction Operation Maintenance Program Activities</p>	Adaptation Options (Examples)		
	ACCOMMODATE/MANAGE <ul style="list-style-type: none"> Increase financial and technical resources for more frequent maintenance and repairs Train waste sorters and educate the public about separating recyclable and compostable material from other waste Maintain collection vehicles to minimize disruptions due to mechanical failures 	PROTECT/HARDEN <ul style="list-style-type: none"> Prevent erosion of landfill slopes, covers, and roads into and around landfills Maintain storm water catchment systems to ensure proper function 	RETREAT/RELOCATE <ul style="list-style-type: none"> Cover threatened landfills and develop new sites in more secure locations
	<ul style="list-style-type: none"> Regularly inspect the integrity of water catchment systems and containment walls, particularly following extreme rain or storm events Continue to monitor landfills for groundwater contamination and cover erosion 		

FURTHER READING

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ENERGY SYSTEMS

ADDRESSING CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE: PREPARING FOR CHANGE

Solar panels in India. Photo Credit: USAID/India



- ▶ Climate change impacts may include damage to energy infrastructure (particularly extraction, generation, and transmission), reducing efficiency, and disrupting operations.
- ▶ These climate change-induced impacts have broader implications for energy services, causing more blackouts, increasing energy prices, and worsening safety hazards, threatening the very elements of development that rely on energy.
- ▶ Adaptation options should be evaluated for both their long-term climate-resilience and low-emission benefits. Energy-related adaptation options range from incentive mechanisms that promote use of energy-efficient building materials to building dikes that protect critical infrastructure.

ENERGY SYSTEMS ARE INTEGRAL TO DEVELOPMENT PRIORITIES

Energy helps to promote economic and social development. The infrastructure that supports energy systems enables populations to receive basic services; helps build industry, tourism, and investment; and supports health, education, and agriculture initiatives.

Energy promotes development and economic growth. For example, energy is essential for operating refrigerators and diagnostic tools that are needed to support well-being in health care centers around the world. Education facilities need energy to power computers, video projectors, printers, lights, and other equipment that support quality education programs. In sum, energy is needed for the design, improvement, and operation of virtually all USAID projects and initiatives as well as those of other development organizations.

Energy is also at the heart of the climate change challenge, as energy consumption and production are key sources of greenhouse gas emissions. So, it is incumbent on development practitioners to support low emissions development through clean and climate-resilient energy systems to ensure lasting project effects.

CLIMATE STRESSORS CAN SIGNIFICANTLY IMPACT ENERGY SYSTEMS

Energy infrastructure is vulnerable to a range of climate stressors, including temperature, precipitation, sea level rise, and extreme events. Specifically,

ENERGY SYSTEMS INCLUDE:

- Extraction, capture, and refinement systems
- Generation systems
- Transmission and distribution systems

ENERGY SYSTEMS SUPPORT:

- Urban and rural programs
- Economic growth and workforce development
- Trade and Investment
- Agriculture, health, and education programs

climate change is expected to change the intensity, frequency, and distribution of extreme heat, precipitation, and storms, exacerbating the vulnerability of energy infrastructure.

Impacts on different types of energy infrastructure include accelerated weathering and an increased likelihood of damage or destruction; operational changes in fuel extraction processes; and reduced generation and/or transmission efficiency. Changes in temperature and precipitation can damage fuel extraction infrastructure and transport pipes, disrupting the energy supply chain. Climate change may also affect the availability and timing of renewable energy supplies. Renewable energy sources will likely be affected in different ways in different locations, with some areas experiencing increases in water, sun, or wind availability and other areas experiencing decreases. Climate change might also exacerbate conflicting demands for energy resources, such as water for cooling, impacting energy production.

Climate change impacts on energy demand may also add stress to energy infrastructure, including changes in energy requirements for residential and industrial cooling and heating, the timing and magnitude of peak demand and adjustments in energy consumption for transportation, construction, and agricultural activities. For example, increases in mean temperature and extreme heat events would greatly increase per capita energy demand, potentially overwhelming supply.

These changes may ripple throughout the economy of developing countries, affecting a broad range of activities. For example, changes in the costs and availability of fuels can affect transportation services used for personal transport, tourism travel, and trade. These effects may create

Table 1. Examples of Potential Climate Change Impacts on Energy Infrastructure and Services

	Extraction, Capture, and Process Equipment	Generation Facilities	Transmission, Distribution, and Transport Infrastructure
Temperature Change	<ul style="list-style-type: none"> • Disruption of extraction operations due to changes in timing or length of extraction season (e.g., permafrost thawing) • Changes in capacity for extraction and processing (e.g., reduced ability of workers to work outside) • Alterations in the distribution of fuel types demanded 	<ul style="list-style-type: none"> • Increased capital costs for building new generation infrastructure to support greater demand • Reduced generation efficiency (e.g., due to increased temperature of cooling water) • Changes in hydropower potential (e.g., changes in snowpack melt) and biomass production • Adjustments in the distribution of types of generation capacity 	<ul style="list-style-type: none"> • Increased thermal expansion of power lines, reducing the amount of power that can be securely transported • Increased capital costs for building new transmission and distribution infrastructure to support greater demand • Change in performance of pipeline systems
Precipitation Change	<ul style="list-style-type: none"> • Stress on water-intensive processes, such as mining, processing, and oil shale resource development 	<ul style="list-style-type: none"> • Increased production limitations due to lack of water; including location and type of generation • Change in hydropower potential, especially with regard to timing 	<ul style="list-style-type: none"> • Disruptions in fuel transportation through damage to infrastructure (e.g., flooding, pipeline damage)
Sea Level Rise and Storm Surge	<ul style="list-style-type: none"> • Permanent and/or temporary inundation of extraction infrastructure, refineries, transportation lines, power plants, renewable energy systems, and transmission and distribution lines, resulting in disruptions to energy services 		
Extreme Events (including wind, ice, dust, and coastal storms)	<ul style="list-style-type: none"> • Disruption of operations (e.g., temporary shutdown) • Damage to and potential destruction of infrastructure 	<ul style="list-style-type: none"> • Damage to generation infrastructure • Change in capacity for solar and wind power 	<ul style="list-style-type: none"> • Damage to power lines • Damage to fuel transportation (e.g., pipes, road, rail, or port)
	<ul style="list-style-type: none"> • Increased health and safety concerns (especially for nuclear energy facilities) • Increase in repair and maintenance costs 		

worldwide disturbances in the supply chain. Other effects include more intense storms that could damage nuclear generation facilities, jeopardizing the health and safety of workers and nearby residents. These risks vary in relative importance, with a range of cost implications, compounding effects, and impacts on development objectives. See Table 1 on the next page for additional examples.

Ultimately, **climate change-related energy impacts will have broad implications on energy services, as well as development objectives.** For example, higher capital and maintenance costs will likely increase the price of energy, forcing those with limited resources to make tradeoffs between important services such as health care, transportation, and energy. System failures caused by climate stress could increase the frequency, intensity, and reach of blackouts. These outages would further stress services and populations that rely on energy for cooking, communication, education, healthcare, and livelihoods.

MAINSTREAMING ENERGY-RELATED ADAPTATION INTO EXISTING PROGRAMS

Adaptation measures can help to mitigate energy-related climate risk, build more resilient projects, and sustain economic growth. When development practitioners understand potential climate impacts, they can more easily identify adaptation priorities, and incorporate these priorities into future projects or integrate them into existing capital improvement and maintenance operations.

A screening process focused on the following four key factors can be used to select adaptation priorities:

- **Criticality** – How important is the energy infrastructure component? Lack of backup for vital infrastructure is critical.
- **Likelihood** – How likely is it that projected climate impacts will affect the energy infrastructure?
- **Consequences** – How significant will the climate impact be on energy services? Will it permanently damage energy transmission or distribution systems?
- **Resources available** – Are financial and technical resources available for retrofits or replacements?






Adaptation options include structural changes (e.g., elevating sub-stations) and operational changes (e.g., adjusting schedules and resources for maintenance and repair). The development of less centralized energy infrastructure, such as solar panels on residences or public buildings, may increase backup options and decrease demand on other energy infrastructure. Demand-side management programs that reduce energy consumption can also relieve pressure on a taxed energy system, resulting in both greenhouse gas mitigation and adaptation.

Adaptations may vary in terms of costs and benefits. For example, if climate information is incorporated into upfront project diagnosis and design, adaptations may require little or no additional funding, yet provide sustained benefits. Conversely, development investment decisions that disregard climate information may result in maladaptive projects, such as the development of a nuclear power plant that is likely to encounter increased storm surge, extreme winds, and decreased cooling water availability. To increase the benefit of projects, both climate-resilience (adaptation) and low-emission approaches (mitigation) should be

considered simultaneously. Table 2 provides an illustrative list of potential adaptation actions, and demonstrates the steps a manager would take using the Climate-Resilient Development (CRD) Framework. For further guidance on the CRD Framework, refer to the Overview.

The effectiveness of all development programs is maximized when consideration of climate risk in energy plans and projects is included. **An integrated, systems-level approach to developing low-emission and climate-resilient energy projects will provide long-term and far-reaching benefits.**

Table 2. Examples of Energy-Related Actions by Project Cycle Stage

Project Cycle Stage	Project Cycle Actions		
	<ul style="list-style-type: none"> Identify energy-related development goals important to the country, community, or sector you are working with Identify inputs and enabling conditions necessary to achieving those goals Consider the impacts of climate and non-climate stressors on those inputs 		
	<ul style="list-style-type: none"> Assess climate impacts and identify energy infrastructure and services with the highest climate risk Evaluate climate-related risks in light of all existing risks to the energy sector Prioritize adaptation needs 		
 Planning Policy Changes Project Development	Adaptation Options (Examples)		
	ACCOMMODATE/MANAGE <ul style="list-style-type: none"> Plan for redundancy to accommodate disruptions in service (e.g., water supply) Consider future fuel and generation demand, availability, and costs in planning Consider less centralized energy systems such as locally installed solar panels 	PROTECT/HARDEN <ul style="list-style-type: none"> Update design standards to improve energy efficiency of residential and commercial buildings and power plant cooling systems Equip plants with technologies that capitalize on water reuse 	RETREAT/RELOCATE <ul style="list-style-type: none"> Integrate sea level rise projections and storm surge actions in coastal siting Plan to locate infrastructure away from high risk areas
 Construction Operation Maintenance Program Activities	Adaptation Options (Examples)		
	ACCOMMODATE/MANAGE <ul style="list-style-type: none"> Increase resources for more frequent maintenance Distribute changes in energy costs over time to avoid large spikes in energy prices Incentivize the use of building materials that reflect heat and facilitate cooling efficiency Install backup systems for critical hospital, home needs Incentivize demand-side management, including off-peak use of non-essential appliances, turning off lights 	PROTECT/HARDEN <ul style="list-style-type: none"> Upgrade existing cooling systems or shift generation to newer facilities with more cooling capacity Add reinforcements to walls and roofs Incorporate structural improvements to transmission Build dikes to contain flooding 	RETREAT/RELOCATE <ul style="list-style-type: none"> Relocate infrastructure that may be significantly impacted by climate stressors Move infrastructure in areas where climate impacts may cause severe safety hazards
	<ul style="list-style-type: none"> Track needs for and efficacy of redundant power systems Monitor changing resource needs and conflicting demands (e.g., cooling water) as conditions change Monitor deterioration of transmission infrastructure 		

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United States Climate Change Science Program (USCCSP), 2007. Effects of Climate Change on Energy Production and Use in the United States. <http://www.climatechange.gov/Library/sap/sap4-5/final-report/sap4-5-final-all.pdf>

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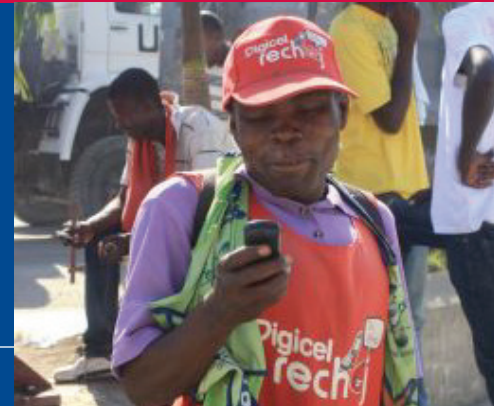
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INFORMATION & COMMUNICATIONS TECHNOLOGY (ICT)

ADDRESSING CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE: PREPARING FOR CHANGE

Phonecard vendor with mobile phone in Port-au-Prince, Haiti. Photo Credit: Jayanthi Narain, USAID



- ▶ Climate changes could impact Information and Communications Technology by overheating data centers, exchanges, and base stations; reducing the strength and quality of wireless signals; and increasing operation and maintenance costs.
- ▶ Climate change impacts on the ICT sector could result in service disruption, infrastructure degradation, and changes in service quality and availability. These impacts can undermine economic activity, emergency response, and social connectivity.
- ▶ ICT-related adaptation options include developing back-up services, planning and preparing for outages, moving above-ground cables below-ground, and relocating critical, coastally located system components.

ICT IS INTEGRAL TO DEVELOPMENT PRIORITIES

USAID and other development practitioners use Information and Communications Technology to address some of the world's greatest development challenges. ICTs, which include radio and television broadcasting, telephone and cell phone communications, and wired and wireless internet, provide basic communication and information dissemination services, enabling people and businesses to prosper economically and connect socially.

By connecting people and making information-sharing easier, ICTs can help reduce poverty, combat disease, and reduce gender inequality. They support economic activities such as online commerce, facilitate emergency response, and provide monitoring and control systems for many sectors. They empower women by providing them with access to information, education, and services—giving them a voice beyond their local community and allowing them to network with other women around the world.

ICTs support climate change resilience and adaptation by educating stakeholders and providing needed information in a timely manner. They can also promote climate change mitigation by improving the efficiency of power systems, transportation, and buildings, and by making their own sector more efficient. Thus, ICTs are affected by climate change, but can also serve as part of the solution, facilitating both mitigation and adaptation.

By investing in low emission, climate-resilient ICTs, USAID and other development practitioners can promote enduring solutions to critical program priorities.

ICT INCLUDES:

- Transmission infrastructure (cables, cell towers, etc.)
- Wireless signals (radio, satellite, microwave, etc.)
- Buildings and equipment (data centers, etc.)
- End-user devices (computers, mobile phones, radios, etc.)

ICT SUPPORTS:

- Education and training
- Economic growth and trade
- Gender equality
- Urban programs
- Disaster risk reduction and management

CLIMATE STRESSORS CAN SIGNIFICANTLY IMPACT ICT SERVICES

Several climate stressors could affect ICT networks and services. They are already vulnerable to weather impacts, including extreme weather events. In addition, ICTs are vulnerable to weather- and climate-related impacts on energy systems and, to a lesser extent, transportation infrastructure. Potential climate change impacts on ICTs vary considerably for below-ground infrastructure, above-ground infrastructure, and wireless-, radio-, or satellite-based services. Below-ground infrastructure could be impacted by flooding, a rise in sea levels, subsidence caused by drought or flooding, and damage to surface infrastructure (such as roads). Above-ground infrastructure could be impacted by changes in precipitation, high winds, and ground instability. Wireless-, radio-, or satellite-based services could be impacted by increasing temperatures, increasing precipitation, and changes in vegetation due to changes in climate. These and other climate change risks vary in relative importance, with a range of cost implications, compounding effects, and impacts on development objectives. Please see Table 1 on the next page for additional examples.

The impacts listed in the table below could degrade infrastructure, disrupt service, reduce service availability and quality, change operating and maintenance costs, and impact workers' health and safety.

Table I. Examples of Potential Climate Change Impacts on ICT Infrastructure and Services¹

	Transmissions Infrastructure	Wireless Signals	Buildings and Equipment ²
Temperature Change	<ul style="list-style-type: none"> Increased heat-related health and safety risks for maintenance workers Sinking and tilting of telecommunications towers due to thawing permafrost 	<ul style="list-style-type: none"> Decreased range of wireless signal transmission, resulting in the location/density of wireless masts becoming sub-optimal Disruptions in wireless signals from changes in vegetation growth due to shifting ecosystems 	<ul style="list-style-type: none"> Overheating of data centers, exchanges, base stations, etc. Increased air-conditioning requirements and costs Decreased heating requirements and costs
Precipitation Change	<ul style="list-style-type: none"> Increased flooding of low-lying/underground infrastructure and access points, particularly in coastal areas, flood plains, and cities Exposed cables/trunk routes due to erosion or damage of transportation infrastructure Reduced maintenance needs for snow-related issues 	<ul style="list-style-type: none"> Reduced quality and strength of wireless service due to increased rainfall 	<ul style="list-style-type: none"> Changes in requirements to maintain internal environments of system devices due to changes in humidity
Increased Sea Level Rise and Storm Surge	<ul style="list-style-type: none"> Increased flooding and salt water corrosion of infrastructure in low-lying/coastal areas 	<ul style="list-style-type: none"> Changes in reference datum for telecommunication and satellite transmission calculations 	<ul style="list-style-type: none"> Closure or reduced access to low-lying coastal buildings due to permanent or temporary flooding
Changes in Extreme Storms and Wind	<ul style="list-style-type: none"> Fallen cell towers or telephone poles from high winds or fallen trees Increased damage to above-ground infrastructure 	Minimal Impact	Minimal Impact

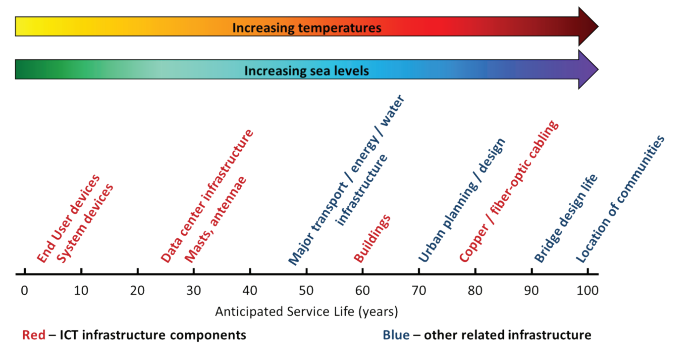
DEVELOPMENT ORGANIZATIONS CAN MAINSTREAM ICT-RELATED ADAPTATION INTO EXISTING PROGRAMS

Unlike other infrastructure categories, many parts of the ICT sector are characterized by rapid development and change. End-user devices have the fastest natural turnover: Data center infrastructure and transmission infrastructure like masts and antennae are also replaced faster than many other infrastructure types. This rapid pace lends itself to flexible, incremental, and almost reactive adaptation to climate change, if climate risks are incorporated into design decisions.

ICT infrastructure with longer lifetimes, such as buildings and cabling, will be less able to incrementally adapt. In general, the longer the anticipated service life of infrastructure, the more important it is to incorporate climate change considerations into planning and design. Figure 1 depicts the anticipated service life of ICT infrastructure components alongside increasing climate change impacts³.

Since adaptation-related actions can be incorporated into existing turnover; the costs for ICT-related adaptation are likely to be relatively modest. However, adaptation could be more costly if important system components (such as network links, nodes, or central offices) are coastally located and need to be fundamentally relocated, rerouted, or otherwise protected from increasing sea levels and storm surges. In addition, more proactive adaptation measures should be considered when designing longer-lived infrastructure components such as buildings and cabling. Adaptation priorities should be selected based on decision makers' assessment of the following four key factors (presented with illustrative questions). Please see the Overview for more information.

Figure 1. Service life (in years) of ICT Infrastructure Components alongside Increasing Climate Change Impacts



- **Criticality** – How important is the infrastructure to the community or region? Is the infrastructure component required for emergency response? Are back-up services available?
- **Likelihood** – Given climate projections, is the component likely to be impacted by climate change?
- **Consequences** – How significant is the impact? Will climate changes permanently or temporarily disrupt communication services? Or will impacts merely result in a reduction in service quality?
- **Resources available** – Can changes be made with only modest cost increases to already-occurring replacement? Does infrastructure have to be replaced prematurely?

USAID and other development practitioners should take advantage of natural development and turnover in the ICT sector by integrating

¹ Table is largely based on Table 4.1 of AEA (2010).






² Note that end-user devices (e.g., mobile phones) are not included in the table. This is because climate change impacts on end-user devices should be minimized by the rapid natural refresh of ICT end-user devices.

³ This figure corresponds to Figure 4.1 of AEA (2010).

adaptation strategies, such as those listed in Table 2, into upfront planning and design. By intentionally integrating climate projections into program development and investment decisions, development practitioners can avoid costly mistakes, such as placing wireless masts at distances where they are not able to accommodate reduced transmission caused by higher

temperatures. While a piecemeal approach to ICT development may result in positive short-term effects, an integrated, climate-resilient approach will maintain value in the longer-term. Table 2 illustrates this approach, aligned with the Climate-Resilient Development (CRD) Framework. See the Overview for further guidance on the CRD Framework.

Table 2. Examples of ICT-Related Actions by Project Cycle Stage

Project Cycle Stage	Project Cycle Actions		
	<ul style="list-style-type: none"> Identify ICT-related development goals important to the country, community, or sector you are working with Identify inputs and enabling conditions necessary to achieving those goals Consider the impacts of climate and non-climate stressors on those inputs 		
	<ul style="list-style-type: none"> Assess climate impacts to ICT infrastructure and services to understand adaptation needs Evaluate criticality of different ICT services to prioritize actions Evaluate climate-related risks within the context of other ICT risks Identify opportunities to reduce dependency of ICT on the power sector 		
 Planning Policy Changes Project Development	Adaptation Options (Examples)		
	ACCOMMODATE/MANAGE <ul style="list-style-type: none"> Develop redundant services to accommodate disruptions Plan ahead for extreme weather events (mobilize extra field crews, store extra back-up power fuel and critical hardware) 	PROTECT/HARDEN <ul style="list-style-type: none"> Update design standards to elevate or otherwise protect critical infrastructure 	RETREAT/RELOCATE <ul style="list-style-type: none"> Plan for coastal infrastructure relocation
 Construction Operation Maintenance Program Activities	Adaptation Options (Examples)		
	ACCOMMODATE/MANAGE <ul style="list-style-type: none"> Increase fuel supplies for back-up power at antennas, cell towers, and central offices Trim trees near cables Educate people on how to prepare for outages 	PROTECT/HARDEN <ul style="list-style-type: none"> Move above-ground cables below-ground Construct protective barriers around critical ICT infrastructure 	RETREAT/RELOCATE <ul style="list-style-type: none"> Relocate or reroute critical system components further inland
	<ul style="list-style-type: none"> Track performance of ICT infrastructure, such as signal strength and communication clarity Monitor changing maintenance needs 		

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FLOOD CONTROL STRUCTURES

ADDRESSING CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE: PREPARING FOR CHANGE

Flood control structure in Iloilo, Philippines. Photo Credit: IRG



- ▶ Changes in climate will threaten the efficacy, adequacy, and durability of flood control structures and their continued services.
- ▶ Since flood control structures provide defense against frequent, small floods in rivers and estuaries, rising sea levels, and storm surges, climate change impacts on these structures may significantly affect the communities relying on their protection. Such impacts have implications for urban stability, economic growth and trade, and food and water availability.
- ▶ These structures and their services can be protected with adaptation strategies that include fortifying existing structures and updating design standards to accommodate future climate changes.

FLOOD CONTROL STRUCTURES ARE INTEGRAL TO DEVELOPMENT PRIORITIES

Flood control structures are designed to protect coastal and river-bank areas, including urban and agricultural communities, homes, and other economically valuable areas, and the people located within them. These structures are used to divert flows of water, by re-directing rivers, slowing natural changes in embankments and coastlines, or preventing inundation of vulnerable coastlines or floodplains. Dikes, spurs, levees, and seawalls often act as the first line of defense against overflowing rivers, floods, storm surges, and—in the longer term—rising seas. By keeping water out, flood control structures lessen harm to physical infrastructure and help to ensure continuation of communities' economic and social activity.

But flood control structures do not completely eliminate risk. Flooding may occur if the design water levels are exceeded. If poorly designed, constructed, operated or maintained, these structures can increase risk by providing a false sense of security and encouraging settlements or economic activity in hazard-prone areas.

Nevertheless, many development programs rely on these structures to maintain program objectives, including continued food and water supplies, economic activity, and protection from storms and floods. For example, urban initiatives (e.g., urban transport projects) in coastal cities like Dhaka, Bangladesh necessarily rely on effective flood control structures, such as pump stations and dikes, to maintain program effectiveness in the short-term. **By supporting the climate-resilient design, construction, and maintenance of flood control structures, USAID and other**

FLOOD CONTROL STRUCTURES INCLUDE:

- Dikes
- Spurs
- Levees
- Seawalls

FLOOD CONTROL STRUCTURES SUPPORT:

- Urban programs
- Economic growth and trade
- Food and water availability

development practitioners can help ensure the lasting effects of development projects and programs in vulnerable areas.

CLIMATE STRESSORS CAN SIGNIFICANTLY IMPACT FLOOD CONTROL STRUCTURES AND THEIR SERVICES

Like many other types of infrastructure, flood control structures are often designed to last several decades. Several climate stressors affect the efficacy and durability of flood control structures, including changes in precipitation, sea levels, extreme events, and resulting storm surges. Flood control structures are unique in that they can be compromised by the same stressors they are designed to withstand. For example, increases in the intensity and frequency of floods could overwhelm these structures, causing them to fail. These stressors will grow in importance as climate change continues to alter their intensity, variability, and accompanying hazard potential.

Potential impacts will depend on a variety of factors that affect the vulnerability of these structures. For example, if sea walls are constructed in areas that are experiencing land subsidence, they will be more vulnerable to storm surges and sea level rise. Climate change risks vary in relative importance, with a range of cost implications, compounding effects, and impacts on development objectives. Failures of flood control structures can result in dire consequences for the services provided and investments made by the development community. Table 1 provides several examples of potential climate change impacts on flood control structures.

Table I. Examples of Potential Climate Change Impacts on Flood Control Structures and Services

	Flood Control Structures and Services
Precipitation Change	<ul style="list-style-type: none"> • Failure of existing flood control structures due to increased flooding from increased precipitation • Weakened embankments or inefficient impervious core due to erosion and liquefaction from recurring, intense flooding
Sea Level Rise	<ul style="list-style-type: none"> • Overflowing of older structures built to standards that do not integrate sea level rise • Weakening of flood control structures due to land subsidence and erosion combined with sea level rise • Inundation of structures in low-lying lands due to failure of flood control structures
Storm Surge	<ul style="list-style-type: none"> • Overpowering of structures due to increased height of waves, tides, and surges • Weakened or damaged structures (e.g., cracks in critical junctures) due to repeated storm surge
Extreme Events	<ul style="list-style-type: none"> • Damage to and destruction of flood control structures due to sudden freeze-thaw cycles or the combined forces of cascading extremes such as cyclones, snowmelt, heavy precipitation • Breaches of structure leading to temporary and permanent inundation

DEVELOPMENT PROGRAMS CAN INCLUDE FLOOD CONTROL STRUCTURE-RELATED ADAPTATION

To reduce climate change impacts on flood control structures and the resulting damage and destruction to coastal and low-lying communities, development practitioners must adapt flood control structures to future climate stressors. Adapting flood control structures will protect investments in a variety of sectors, including transportation, energy, and urban programs.

The resilience of flood control structures can be increased in many ways. For example, flood control structures should be built to higher levels and with more resilient materials and designed to withstand repeated and more extreme floods. Similarly, in designing flood control structures, USAID and other development organizations should consider, where feasible, constructing back-up structures to provide services in case of failure. In addition, design standards should incorporate sea level rise projections, as well as the hydrology and physiography of the watershed to minimize or avoid unintended adverse impacts.

It is critical that trained and registered engineers design, implement, and review new construction and improvements to ensure stability, since untested flood control structures may constitute a direct threat to human life. In addition, communities should avoid promoting an unfounded sense of security as any structure may fail in extreme circumstances.

To understand the implications for flood control structures, decision makers should identify plausible future climate scenarios to understand how relevant factors—such as sea levels and extreme event intensity—are projected to change. Using this information, decision makers can identify needed changes to the design, construction, and maintenance of structures. Development practitioners must understand the vulnerabilities of different structures, based on location, design, and construction in






addition to hydrologic, environmental, and ecosystem impacts. Adaptation actions should be integrated into the overall risk management strategy for flood control structures.

Adaptation priorities should be selected based on decision-makers' assessment of the following four key factors (presented with illustrative question; refer to Overview for further guidance):

- **Criticality** – What is the hazard potential of failure of these structures, including population and value of assets in the area protected by the structures?
- **Likelihood** – Given climate projections, how likely is it that this structure will be weakened or overwhelmed by climate change?
- **Consequences** – Will climate changes lead to breach, overtopping, or complete failure of these structures or destabilize the embankments? If the structure fails, what damage and destruction will ensue?
- **Resources available** – Can the structure be fortified at low cost? Do new structures need to be built to provide adequate protection services? Are there certified specialized engineers to design, construct, inspect, and maintain these structures in the target areas?

An integrated, climate-resilient approach to flood control management will ensure that development program outcomes are durable and long-lasting. Climate change projections should be deliberately and knowledgeably included in the various project cycle stages, including the design, construction, and maintenance of flood control structures. Different options exist to mitigate the impacts of these climate stressors, including structural changes (e.g., changes to embankment slopes) and policy changes (e.g., changes to zoning codes, relocation, designing redundancy plans). Table 2 provides illustrative examples of adaptation options for flood control structures, and shows the overall approach to assessing and addressing climate risks using the Climate-Resilient Development (CRD) Framework. See the Overview for further guidance.

Table 2. Examples of Flood Control-Related Actions by Project Cycle Stage

Project Cycle Stage	Project Cycle Actions		
	<ul style="list-style-type: none"> Identify flood control-related development goals important to the country, community, or sector you are working with Identify inputs and enabling conditions necessary to achieving those goals Consider the impacts of climate and non-climate stressors on those inputs 		
	<ul style="list-style-type: none"> Assess climate impacts to understand how the design, construction, and maintenance of flood control structures may need to change Evaluate climate-related risks amidst all existing risks to flood control structures and associated services Evaluate social, hydrologic, environmental, and ecosystem impacts of the proposed action Evaluate non-climatic factors, such as land use changes, to understand how they may ameliorate or exacerbate effects from floods 		
 <p data-bbox="126 638 310 709">Planning Policy Changes Project Development</p>	Adaptation Options (Examples)		
<p data-bbox="347 512 639 533">ACCOMMODATE/MANAGE</p> <ul style="list-style-type: none"> Develop redundant structures or services that can be relied upon if structures fail Increase inspection frequency to ensure structures are enduring climate change pressures Design flood risk-management plans with both ecosystem- and construction-based adaptation options 	<p data-bbox="755 512 964 533">PROTECT/HARDEN</p> <ul style="list-style-type: none"> Update design standards to integrate projected sea level rise and storm surge Fortify embankments to counteract effects of increased coastal erosion 	<p data-bbox="1141 512 1360 533">RETREAT/RELOCATE</p> <ul style="list-style-type: none"> Plan for community relocation Explore natural resource management approaches to increase storage in the watershed or break waves, such as establishment of mangroves Update zoning codes for coastal land to establish natural buffer zones 	
 <p data-bbox="142 907 293 1003">Construction Operation Maintenance Program Activities</p>	Adaptation Options (Examples)		
<p data-bbox="347 823 639 844">ACCOMMODATE/MANAGE</p> <ul style="list-style-type: none"> Increase resources for more frequent maintenance and repairs Temporarily evacuate areas Use ecosystem options (e.g., riparian buffers) to naturally absorb excess water 	<p data-bbox="755 823 964 844">PROTECT/HARDEN</p> <ul style="list-style-type: none"> Use permeable materials in select locations to allow for better absorption of water Use improved asphalt/concrete mixtures 	<p data-bbox="1141 823 1360 844">RETREAT/RELOCATE</p> <ul style="list-style-type: none"> Relocate communities further inland or away from flood basins 	
	<ul style="list-style-type: none"> Track performance of flood control structures and assess whether additional redundant services or other options are required Monitor changing environmental conditions affected by climate, including changes in storm surge levels, wind speed, and precipitation 		

FURTHER READING

British Columbia Ministry of Environment, 2011. Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use. Available at http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/draft_policy_rev.pdf

U.S. Army Corps of Engineers, 2011. USACE Climate Change Adaptation Plan and Report 2011. Available at http://www.corpsclimate.us/docs/usace_climate_change_adaptation_report_03_june_2011.pdf



CULTURAL HERITAGE ASSETS

ADDRESSING CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE: PREPARING FOR CHANGE

Roof built to protect SOLI Basilica mosaics in Cyprus. Photo Credit: Glen Anderson, 2008



- ▶ Climate change impacts include erosion of structures and decorated surfaces, flooding of buildings, and salt weathering of irreplaceable historic and archeological materials.
- ▶ Since cultural heritage assets are critical to the preservation of cultural values and identity and often play a key role in supporting regional economies, climate change impacts on these assets may have far-reaching effects on development programs.
- ▶ Cultural heritage adaptation options include maintaining and reinforcing structures, monuments, and buildings; building dykes or dams to protect sites; or moving cultural heritage infrastructure and artifacts from low-lying areas.

CULTURAL HERITAGE ASSETS ARE INTEGRAL TO DEVELOPMENT PRIORITIES

Cultural heritage assets help provide and preserve social, cultural, and educational resources. The often irreplaceable buildings, monuments, and settlements contribute to tourism and economic development, resulting in job creation and income generation.

USAID missions and other development practitioners work with local organizations to preserve cultural heritage and support the development and use of conservation skills. **By protecting cultural heritage and supporting sustainable tourism, development practitioners can also enhance future economic opportunities.**

CLIMATE STRESSORS CAN SIGNIFICANTLY IMPACT CULTURAL HERITAGE ASSETS

Climate stressors can directly affect cultural heritage buildings, monuments, and settlements. Sea level rise threatens coastal assets with increased erosion and salt water intrusion. More frequent and intense storms and flood events can damage structures that were not designed to withstand prolonged structural pressure, erosion, and immersion. Changing precipitation patterns can quickly erode assets built for a different climate. For example, buildings in the rare medieval city of Leh in Ladakh, India, were constructed in a high altitude desert environment and are ill suited to current increases in precipitation. Increases in soil moisture due to increased precipitation can reduce the physical stability of historic buildings and archeological remains. Warmer temperatures and increased humidity

CULTURAL HERITAGE ASSETS INCLUDE:

- Monuments
- Historic structures and settlements
- Places of worship
- Cemeteries
- Archeological sites

CULTURAL HERITAGE ASSETS SUPPORT:

- Education
- Cultural and social development
- Economic growth

can damage building materials and structures by encouraging rot, pest infestations, and erosion. Drought, warmer temperatures, salt weathering, and erosion threaten cultural heritage assets in desert areas such as the Chinguetti Mosque in Mauritania, built with dry stone and mud brick. These and other climate change risks vary in relative importance, with a range of cost implications, compounding effects, and impacts on development objectives. Please see Table 1 for additional examples.

DEVELOPMENT ORGANIZATIONS CAN INTEGRATE CULTURAL HERITAGE-RELATED ADAPTATION INTO EXISTING PROGRAMS

USAID, other development practitioners, and local decision-makers can identify adaptation action priorities and integrate them into existing improvement and maintenance programs. Through a screening process, adaptation priorities may be selected based on local decision-makers' assessment of the following four key factors (presented with illustrative questions). Table 2 provides an illustrative list of potential adaptations. For more information, please refer to the Overview.

- **Criticality** – Is the cultural heritage asset important to the area's history and the people's sense of identity? Is the asset an important tourist attraction?
- **Likelihood** – What is the probability that climate change will impact the cultural heritage asset?

Table I. Examples of Potential Climate Change Impacts on Cultural Heritage Assets and Artifacts¹

	Artifacts, Structures, Buildings, and Settlements
Temperature Change	<ul style="list-style-type: none"> • Deterioration due to thermal stress and biochemical activity • Damage due to increased pest frequency • Damage from freeze-thaw cycles or frost • Damage inside brick, stone, and ceramics in which water freezes before drying • Overheating of the interior of buildings and artifacts, which leads to inappropriate alterations to materials
Precipitation Change (including glacial melt)	<ul style="list-style-type: none"> • Loss of stratigraphic integrity due to cracking and heaving from changes in sediment moisture • Physical changes to porous materials and finishes due to rising humidity • Crystallization and dissolution of salts from wetting and drying affecting standing structures, archaeology, wall paintings, frescos, and other decorated surfaces • Erosion and corrosion of metals due to flood waters • Biological attack of organic materials by insects, molds, fungi, and invasive species such as termites • Splitting, cracking, flaking, and dusting of materials and surfaces from changing relative humidity cycles
Sea Level Rise	<ul style="list-style-type: none"> • Erosion or loss of sites • Saltwater intrusion of subsurface structures • Permanent inundation of resources in low-lying areas
Wind	<ul style="list-style-type: none"> • Penetrative moisture into porous materials • Structural damage and collapse • Deterioration of surfaces due to erosion
Desertification	<ul style="list-style-type: none"> • Erosion • Salt weathering • Collapse of structure

- **Consequences** – Will the consequences of climate change impacts permanently destroy irreplaceable heritage assets? Is the damage repairable?
- **Resources available** – Can existing heritage assets be preserved at costs within the government's budget? Is a gradual timeline required to restore and protect assets?

For example, in Bangladesh, the historic city of Sonaragaon contains thousands of elaborate buildings from the Middle Ages. The buildings are already deteriorating due to lack of maintenance, as well as sea level rise and flooding caused by loss of natural barriers such as mangrove forests. Future sea level rise could lead to more intense flooding that would lead to further loss of cultural heritage, as well as the displacement of significant numbers of people. Decision makers should consider these climate change impacts, consequences, and necessary resources to adequately raise awareness of current and future threats, build capacity, and protect and maintain the site.

Cultural heritage-related adaptation options include: increasing necessary skillsets among stakeholders; changing management practices and policies related to infrastructure maintenance, reinforcement, and development to protect and fortify structures; and developing partnerships that include benefits sharing, since the people seeking to preserve a site may be different from those whose actions are required to protect it. Some adaptation strategies may require little or no additional funding, if climate factors are incorporated into upfront planning and design, while others may require significant additional resources. Mainstreaming adaptation






strategies into existing cultural heritage management plans and programs can strengthen long-term preservation efforts.

When cultural heritage assets are rehabilitated, renovated, and monitored, all relevant long-term factors should be taken into account. For example, there are three World Heritage sites along the River Thames in and near London. When assessing the capacity of the Thames barrier to protect the city from flooding, city officials are considering the protection of property and people as well as the preservation of the World Heritage sites. This effort requires analyzing existing data, as well as monitoring and predicting changes in surface water levels, sea level, and precipitation due to climate change. This assessment can be done in conjunction with other city and adaptation planning.

While some adaptation measures for cultural heritage assets are similar to those for other kinds of infrastructure, cultural heritage assets also present unique challenges. For example, cultural heritage assets are generally not replaceable. In addition, some adaptation strategies are specific to heritage assets, such as combining traditional materials and skills with modern engineering when reinforcing, stabilizing, and renovating historic assets to both preserve their historic aesthetics and enhance their longevity. Adaptation options also differ depending on whether the cultural heritage asset can or cannot be relocated. Table 2 presents examples of the variety of adaptation options that may be appropriate during the Design and the Implement and Manage stages of the Climate-Resilient Development (CRD) Framework. See the Overview for further guidance on the CRD Framework.

¹ Adapted from (UNESCO), 2007. World Heritage Reports 22 - Climate Change and World Heritage: Report on predicting and managing the impacts of climate change on World Heritage and Strategy to assist States Parties to implement appropriate management responses. Colette, A. (ed). UNESCO World Heritage Centre.

Table 2. Examples of Cultural Heritage-Related Actions by Project Cycle Stage

Project Cycle Stage	Project Cycle Actions
	<ul style="list-style-type: none"> Identify cultural heritage-related development goals important to the country, community, or sector you are working with Identify inputs and enabling conditions necessary to achieving those goals Consider the impacts of climate and non-climate stressors on those inputs
	<ul style="list-style-type: none"> Assess climate threats, impacts, and vulnerabilities to understand adaptation needs Evaluate climate-related risks in light of all existing risks to cultural heritage resources
 <p>Planning Policy Changes Project Development</p>	<p style="text-align: center;">Adaptation Options (Examples)</p> <ul style="list-style-type: none"> Develop multilateral environmental agreements and build partnerships and networks to facilitate development and implementation of adaptation strategies, monitoring, and evaluation efforts Plan for emergency preparedness
 <p>Construction Operation Maintenance Program Activities</p>	<p style="text-align: center;">Adaptation Options (Examples)</p> <ul style="list-style-type: none"> Regularly maintain and restore cultural heritage structures, buildings, and settlements Reinforce dikes and drainage systems to deal with rising sea levels and intense rainfall events Relocate artifacts and structures out of low-lying, high risk areas Regulate water inflow or outflow with dams and anti-flood protection Replace historic water disposal and capture systems that are not capable of handling heavy rainfall Create boundaries and buffer zones to protect buildings and structures from sand encroachment Implement multilateral initiatives to support adaptation efforts for cultural heritage Increase awareness on climate change challenges, best practices, research, and adaptation Train stakeholders, decision-makers, and local communities on management, emergency preparedness, and monitoring Conduct research to support national and regional decision-making Support traditional practices and materials
	<ul style="list-style-type: none"> Track performance of adaptation actions and assess the need to develop and implement new or improved methods such as repairing older materials or replacing them with similar, more resilient materials Conduct ongoing mapping, monitoring, and reporting on the rate and intensity of climate impacts on cultural heritage assets, including: cracks in structures, buildings, or monuments; storm tide and wave activity around low-lying coastal structures and sites; efficacy of rainwater drainage systems; efficiency of buffer zones; and weathering on the surface of structures

FURTHER READING

United Nations Educational, Scientific, and Cultural Organization (UNESCO), 2007. World Heritage Reports 22 - Climate Change and World Heritage: Report on predicting and managing the impacts of climate change on World Heritage and Strategy to assist States Parties to implement appropriate management responses. http://whc.unesco.org/documents/publi_wh_papers_22_en.pdf

UNESCO, 2007. Case Studies on Climate Change and World Heritage. <http://unesdoc.unesco.org/images/0015/001506/150600e.pdf>



BUILDINGS

ADDRESSING CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE: PREPARING FOR CHANGE

Gueckedou Hospital in Guinea. Photo Credit: USAID/Plan Guinea



- ▶ Changes in climate, such as sea level rise and more intense storm events, increase the risk of damage and destruction to buildings, threatening their stability, services, and operations.
- ▶ Because buildings often serve as a foundation for development projects, climate change impacts may have far-reaching and unexpected implications for economic and social development initiatives.
- ▶ To protect building infrastructure, operations, and services, risk-reducing adaptation measures should be considered in all stages of the project cycle. Adaptation options range from changing maintenance schedules to using wide storm gutters to substantial renovation or relocation.

BUILDINGS ARE INTEGRAL TO DEVELOPMENT PRIORITIES

Buildings act as a hub for activities that support sustained and equitable economic and social development at all scales.

- Public buildings provide the infrastructure and operations needed to support democracy and supply essential services, such as education, health, public policy, and civil protection.
- Industrial and commercial infrastructure enables enterprise development and helps to create and maintain industry, trade, investment, workforce development, food supply, and domestic and international markets.
- Housing infrastructure helps to fulfill basic needs for shelter and protection, generate employment opportunities, improve public health, and support the development of stable communities.

Buildings are critical components to most development programs. For example, in order to effectively promote democracy and representative governance, development practitioners need to ensure the availability of buildings that enable interaction between public agencies and civil society organizations.

However, buildings and their operations are also a source of greenhouse gas emissions and contribute significantly to climate change. **By supporting safe, low emission, and climate-resilient buildings and operations, USAID and other development practitioners will facilitate the provision of dependable and sustainable services that are vital to economic growth and a well-functioning society.**

BUILDINGS INCLUDE:

- **Public Buildings**
 - Schools, hospitals, and health centers
 - Other service buildings (government offices, fire and police stations, post offices, etc.)
- **Industrial and Commercial Infrastructure**
 - Buildings and structures
 - Heavy machinery and equipment
- **Housing**
 - Single- and multi-family homes
 - Apartments and condominiums
 - Informal settlements

BUILDINGS SUPPORT:

- Economic growth and trade
- Humanitarian assistance and food security
- Education, health, and urban programs
- Tourism, enterprise, and workforce development
- Democracy and governance

CLIMATE STRESSORS CAN SIGNIFICANTLY IMPACT BUILDINGS AND THEIR SERVICES

Buildings are typically designed for a specific climate and are constructed to last for decades. However, climate change will alter current conditions, challenging buildings to operate under a wider range of climatic conditions that may push the boundaries of current design standards. A number of climatic changes such as temperature, precipitation, sea level rise, and extreme events, will affect building infrastructure and operations. An extreme event, for example, may cause deterioration or damage to the interior or exterior of a police station or factory, and the equipment located within these buildings. Alternatively, intense precipitation may cause flooding or washing out of poorly constructed or situated settlements.

High temperatures and heat waves will cause internal building temperatures to increase, particularly when combined with the urban heat island effect in cities. This may result in heat stress, health problems, and loss of productivity for those who inhabit the buildings. More humid weather will affect buildings in warm weather climates, such as southern

Table I. Examples of Potential Climate Change Impacts on Building Infrastructure and Operations

	Infrastructure	Operations
Temperature Change	<ul style="list-style-type: none"> Increased cooling demand Premature deterioration of structures/equipment from thermal stress (freeze-thaw cycles, solar radiation, etc.) Changes in the dimension/shape of building materials and equipment from cracking and fissuring Insect infestations, e.g., termites, impacting building structures and worker health 	<ul style="list-style-type: none"> Changes in internal temperatures causing heat stress, health problems, or reduced productivity for workers Damage to temperature-sensitive infrastructure that support operations (electrical systems, etc.) Impacts on use of building equipment, including heating, cooling, waste, and water systems Disruptions in construction/maintenance activities and supply chains (transport networks, etc.)
Precipitation Change	<ul style="list-style-type: none"> Increase precipitation may result in: <ul style="list-style-type: none"> Seepage and flooding in building interior Physical changes to building materials (e.g., corrosion of metals) and finishes Washout of temporary or poorly-constructed housing structures Decreased precipitation may result in: <ul style="list-style-type: none"> Increased soil cracking and subsidence in areas with clay soils and reduced soil moisture Damage to building foundation and façade from ground movement and subsidence 	<ul style="list-style-type: none"> Impacts on health, safety, and well-being of workers caused by deposits of fungi, mold, and chemicals Disruptions in maintenance, repair, and supply chains due to flooding/inundation Inadequately functioning and/or stressed water and waste systems
Sea Level Rise and Storm Surge	<ul style="list-style-type: none"> Closure and/or diminished access to low-lying coastal buildings due to permanent inundation or temporary flooding Waste containment problems Increased salt water intrusion into water supplies 	
Extreme Events (including wind, ice, dust, and coastal storms)	<ul style="list-style-type: none"> Structural damage due to changes in intense weather patterns Reduced durability of exterior surfaces due to erosion and weathering Accelerated deterioration of building shells due to an increase in particulate matter, smoke 	<ul style="list-style-type: none"> Disruptions in operational activities and supply chains Increased safety hazards and physical damage to service workers Increased disturbance to operational support services (e.g., stormwater and electricity systems)

India. Sea level rise could permanently inundate homes, workplaces, or service centers. Flooded coastal health centers could hamper delivery of critical health services, such as distribution of malaria medication buildings in warm weather climates, such as southern India. Sea level rise could permanently inundate homes, workplaces, or service centers. Flooded coastal health centers could hamper delivery of critical health services, such as distribution of malaria medication.

Table I illustrates how climate factors may impact building infrastructure and operations. Impacts include structural damage, reduced building lifetime, and increased stress to operations. These impacts can have severe implications for building infrastructure, operations, and services; potential implications include loss of building value, higher repair and maintenance costs, increased health and safety concerns, and elimination or interruption of services or production.

Climate change risks vary in relative importance, with a range of cost implications, compounding effects, and impacts on development objectives. By damaging facilities or disrupting activities, **climate change impacts on buildings can have far-reaching implications for safety, economic growth, poverty reduction, and other development objectives.** For example, a loss of industrial agriculture processing capability could affect food markets by reducing access and increasing prices. These effects, in turn, will likely have disproportionate impacts on the most impoverished populations.

DEVELOPMENT ORGANIZATIONS CAN MAINSTREAM BUILDING-RELATED ADAPTATION INTO EXISTING PROGRAMS

Adaptation measures can help address the potential impacts discussed above. For example, better risk management systems can reduce potential liabilities and protect project investments, building inhabitants, and the provision of services. Planning for an increase in temperature would help to ensure the comfort, health, and productivity of staff and service recipients, thus retaining service providers and protecting beneficiaries. To protect building infrastructure, operations, and services, development practitioners must recognize areas that climate change may impact and identify adaptation priorities that will cost-effectively reduce those impacts. Adaptation priorities should be incorporated into the design phase of new projects and integrated into the capital improvement plans and maintenance cycles of existing projects.

Decision makers should consider four key factors when prioritizing adaptation measures (refer to the Overview for further guidance):

- **Criticality** – How important are the buildings for achieving development objectives, such as education, employment, or economic growth? Are the buildings required during emergencies?
- **Likelihood** – Given climate scenarios, are the buildings likely to be impacted by climate change?
- **Consequences** – How severely will the building infrastructure or operations be affected? Will climate change impacts permanently or temporarily disrupt the use of buildings?






- **Resources available** – Can adaptation measures be incorporated into ongoing maintenance and renovation plans? Are substantial investments required to retain use of the buildings?

Development practitioners can employ a range of adaptation actions that reduce the vulnerability of building infrastructure and operations to climate change impacts. Actions include operational and policy changes such as increases in maintenance activities, development of risk management protocols, or support of flexible dress requirements that allow for climate-appropriate attire. Other options are structural changes such as alterations in building and equipment materials, moving electrical infrastructure above flood levels, or use of deeper foundations. Some adaptation strategies, particularly changes in building materials and design, are proactive and should be considered in the project design stage. Other adaptation strategies, like renovating exterior landscapes, can be implemented over time and as conditions evolve. Table 2 provides an illustrative list of

adaptation measures related to buildings that may be appropriate during the Design and the Implement and Manage stages of the Climate-Resilient Development (CRD) Framework. See the Overview for further guidance on the CRD Framework.

By integrating climate information into the project cycle, USAID and other development practitioners can make smart investments that will sustain value into the future and avoid maladaptive projects, such as developing a hotel to support tourism in a low-lying coastal area exposed to sea level rise. Development practitioners should also prioritize strategies that simultaneously reduce vulnerability and mitigate greenhouse gas emissions to ensure a sustainable, clean, and resilient approach with expansive benefits. While an ad-hoc approach to building infrastructure may result in positive short-term effects, an integrated, climate-resistant approach will maintain value in the longer-term. policy changes (e.g., changes to zoning codes, relocation, designing redundancy plans).

Table 2. Examples of Building-Related Actions by Project Cycle Stage

Project Cycle Stage	Project Cycle Actions		
	<ul style="list-style-type: none"> • Identify building-related development goals important to the country, community, or sector you are working with • Identify inputs and enabling conditions necessary to achieving those goals • Consider the impacts of climate and non-climate stressors on those inputs 		
	<ul style="list-style-type: none"> • Use climate impact assessment to identify locations and communities with the highest climate risk • Prioritize adaptation needs and develop a strategy • Evaluate climate-related risks in light of all existing risks to building infrastructure, operations, and services 		
 <p>Planning Policy Changes Project Development</p>	Adaptation Options (Examples)		
	ACCOMMODATE/MANAGE <ul style="list-style-type: none"> • Integrate climate projections into project development and operations planning • Develop effective emergency response protocols that will reduce liabilities and protect service providers • Embed climate-related liabilities in property sector contracts to institutionalize protection of facilities • Prepare for disruptions by developing contingency plans • Reconsider zoning and planning regulations to appropriately locate housing structures in “safe” or less vulnerable zones 	PROTECT/HARDEN <ul style="list-style-type: none"> • Update/amend design standards to accommodate future climate conditions • Plan to construct buildings with resilient designs and materials (e.g., use enhanced or piled foundations, have less area to heat/cool, or require less water). Specific measures include changing building orientation and size, installing low flow toilets, laying deeper foundations • Incorporate flexibility in building design to allow for future trends and innovations 	RETREAT/RELOCATE <ul style="list-style-type: none"> • Site new buildings in low risk areas • Plan for relocation of buildings located in high risk areas • Convert coastal land uses to establish natural buffer zones
 <p>Construction Operation Maintenance Program Activities</p>	Adaptation Options (Examples)		
	ACCOMMODATE/MANAGE <ul style="list-style-type: none"> • Purchase insurance to protect against unexpected damage or destruction • Adjust operations to accommodate more frequent maintenance (e.g., clean drainage gullies and gutters) • Communicate risk management protocols that will reduce liabilities and protect workers during extreme events • Keep emergency preparedness materials (like sandbags) on site 	PROTECT/HARDEN <ul style="list-style-type: none"> • Use reinforced materials in constructing houses (concrete, brick, etc.) • Strengthen foundations of housing structures • Incorporate additional water/energy capacity • Build levees, use permeable pavement, and plant vegetation to reduce flooding • Retrofit roofs to reflect heat (e.g., replace black roofs with green or brown roofs) • Install mechanical systems to prevent dampness and mold 	RETREAT/RELOCATE <ul style="list-style-type: none"> • Relocate buildings away from coastal areas that are vulnerable to sea level rise, as well as flood-, fire-, and landslide-prone areas • Temporarily close buildings and relocate services in the event of extreme weather and/or damage • Elevate electrical equipment and structures above flood and sea levels
	<ul style="list-style-type: none"> • Track performance of adaptation measures by monitoring building-related indicators (internal temperatures, air flows, etc.) • Monitor changing environmental conditions affected by climate • Track efficacy of new maintenance schedules • Implement additional adaptation actions where needed 		

FURTHER READING

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