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TECHNICAL REPORT

CLIMATE CHANGE AND WATER

AN ANNEX TO THE USAID CLIMATE-RESILIENT DEVELOPMENT FRAMEWORK

DECEMBER 2014
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ACRONYMS

AWWA	American Water Works Association
CCS	carbon capture and storage
DEWATS	decentralized wastewater treatment system
GAC	granular activated carbon
GHG	greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GLOF	glacial lake outburst flood
GTZ	Deutsche Gesellschaft für Technishe Zusammenarbeit
IPCC	Intergovernmental Panel on Climate Change
IWA	International Water Association
IWRM	integrated water resources management
LEED	Leadership in Energy and Environmental Design
MDG	Millennium Development Goal
MENA	Middle East and North Africa
MIWD	Metro Iloilo Water District
NAPA	National Adaptation Programme of Action
NRW	non-revenue water
OKACOM	Okavango River Basin Water Commission
O&M	operations and maintenance
PAGASA	Philippine Atmospheric, Geophysical & Astronomical Services Administration
PRECIS	Providing Regional Climates for Impacts Studies
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
WDM	water demand management
WEAP	Water Evaluation and Planning
WHO	World Health Organization
WMF	Water Management Forum

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EXECUTIVE SUMMARY

Adequate, safe, and reliable freshwater is an essential foundation for society and development. This annex serves as a sector-specific elaboration of the United States Agency for International Development (USAID, 2014b) climate-resilient development framework. The purpose of this water sector annex is to help development practitioners integrate climate concerns into strategies, programs, and projects for the water sector.

Water managers have a long history of planning for trends such as future population growth, land use changes, and climate variability such as floods and droughts. However, by using the past as a guide to the future, most of this planning implicitly assumed that climate would not change. Most water managers now recognize the scientific consensus that the climate is changing, and those changes need to be considered in water resources planning and management.

Projections of climate variability and change indicate significant impacts to freshwater resources from increasing temperatures, changing precipitation patterns, sea level rise, and more intense extreme events like heat waves, droughts, and floods. These impacts can be succinctly summarized as having too much water (i.e., flooding), too little water (i.e., droughts), and degraded water (i.e., low water quality). These impacts will affect all aspects of water resources – including water supply, sanitation, agriculture, food security, land use, forestry, human health, settlements, infrastructure, ecosystems, fisheries, biodiversity, energy, and more. Understanding the implications of climate variability and change is critical for long-term success in managing, planning for, funding, or operating a water resource or a resource dependent upon or affecting water.

It is important to recognize that taking climate variability and change into consideration does not require a vastly different manner of thinking or doing business. While some actions to address climate variability and change will tackle new issues, most will likely address existing climate stressors such as floods and droughts; non-climate stressors such as water insecurity, population growth, and land use change remain extremely important. Adaptation actions can be developed to create a water system that is both more resilient to existing stressors and better prepared for projected climate impacts. Nevertheless, some aspects of climate change can pose serious risks to many water systems and may require more significant changes, especially where long-lived and high-cost infrastructure investments are under consideration.

There are several key strategies for incorporating climate variability and change into water resources management. Each bullet below summarizes a strategic-level best practice for managing the impacts of climate change that has been successful in other sectors, in other regions, and at various levels of government.

- Mainstream adaptation to climate vulnerability and incorporate into existing decision-making processes (related here to water management) to avoid disruption, duplication, and resource waste.
- Prioritize adaptation actions that will pay dividends regardless of what happens with future climate (i.e., "no-regret" options).
- Initiate adaptation actions that provide benefits under a variety of plausible future climate conditions to account for scientific uncertainty.
- Explicitly address climate variability and change in all relevant management, planning, and operational decisions.
- Manage adaptively to preserve flexibility to adjust policy over time as conditions change or information evolves.

- Examine best practices on climate adaptation from other sectors, levels of government, and regions to learn from related experience.
- Work to remove barriers (e.g., laws, funding mechanisms, and management approaches that were developed without consideration of potential climate impacts or stressors) that discourage or prohibit adaptation to a changing climate or that incentivize increased climate vulnerability.
- Develop adaptation actions that are sensitive to different capacities and limitations at the various geographic, temporal, and decision-making scales where climate impacts occur.
- Look for opportunities presented by climate variability and change, instead of focusing exclusively on negative impacts on water resources and development.

This annex is designed to provide water managers and development practitioners with a comprehensive yet succinct summary of climate variability and change and the challenges it poses for freshwater resources and development. This is followed by a short discussion of categorical adaptation actions that can reduce water resources vulnerability and increase system resilience, not just to climate change, but to existing climate and non-climate stressors as well. Finally, this water annex operationalizes and provides the substantive detail necessary to effectively use United States Agency for International Development's new climate-resilient development framework (USAID, 2014b).

This annex is structured as follows:

- ***Section 1*** introduces readers to the annex and explains its purpose and relationship to other USAID documents.
- ***Section 2*** briefly describes water resources and the six sectors used in this annex to help organize the analysis of water resources and climate vulnerability.
- ***Section 3*** identifies climate stressors, such as projected changes in precipitation and soil moisture, which are anticipated to place new pressures on water resources systems.
- ***Section 4*** identifies major non-climate stressors, such as changes in population growth and urban development, which already place pressure on water resources systems.
- ***Section 5*** projects the impacts that climate stressors are anticipated to have on the water resources sectors defined in Section 2.
- ***Section 6*** assesses water and governance issues.
- ***Section 7*** analyzes some best practices, lessons learned, and principles of adaptation for thinking through the problem as gleaned from other regions and sectors.
- ***Section 8*** identifies a set of proposed adaptation actions; these are described in more detail in Appendix A to this document.
- ***Section 9*** suggests resources for further reading. Many of these resources have been cited throughout this annex, but additional resources are included that may be of interest to development practitioners.
- ***Appendix A*** provides detailed descriptions of the categorical actions in Section 8.

1. INTRODUCTION

UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT (USAID) STRATEGIES AND INITIATIVES ON WATER AND ADAPTATION

- *USAID Climate Change and Development Strategy: 2012–2016* (January 2012)
  - Sets three strategic objectives for USAID, including "Increase resilience of people, places, and livelihoods through investments in adaptation"
- *USAID Water and Development Strategy: 2013–2018* (Undated)
  - USAID's first global strategy emphasizing the sustainable use of water to save lives, promote sustainable development, and achieve humanitarian goals
- Senator Paul Simon Water for the Poor Act: Report to Congress (June 2009)
  - Annual report to Congress by the Secretary of State in consultation with USAID to describe U.S. strategy and progress in achieving the objectives of the Water for the Poor Act
- Addressing Water Challenges in the Developing World: A Framework for Action (March 2009)
  - This framework lays out guiding principles for U.S. foreign assistance in the water sector, setting forth an overarching strategic structure for all U.S. government water sector investments

1.1 WHY SHOULD I BE CONCERNED ABOUT CLIMATE CHANGE AMONG SO MANY OTHER IMPORTANT ISSUES?

Water managers in developing countries already face many challenges, including rapid urbanization, dramatic population growth, population migration, significant land use and land cover changes, and major development and infrastructure deficits. Furthermore, water managers need to prepare for uncertain year-to-year variability in precipitation and runoff, changing water demands related to population growth and land use changes, and numerous other factors that affect water supply, water quality, and flooding. The job of managing water is already a complicated one, and addressing existing development challenges remains critical.

In recent decades, however, the international water sector has started coming to terms with one very important additional factor in water sector planning, management, and operations – namely, changing climate conditions. Many professionals in the water sector now broadly recognize climate change as an important consideration to address in responsible and responsive water resources management and planning. Simply put, water managers can no longer use past climate as a guide to plan for the future. Future weather patterns are projected to differ substantially from the past in many locations, as described in detail below. The implications for freshwater resources from increasing temperatures, changing precipitation, sea level rise, and more extreme events like droughts and floods can be profound. Although water sector management has a long history of vulnerability assessment and risk management, the climate factor adds a new dimension to these established practices.

A CLIMATE WAKEUP CALL IN MINDANAO, PHILIPPINES

Tropical storm Sendong was not a particularly strong storm, but in December 2011, it brought a record-breaking 184 cm of rainfall in just 24 hours to Cagayan de Oro in Mindanao, washing out settlement areas, destroying the city's main piped water source, and resulting in more than 1,200 deaths. Flood warnings were issued but they were not heeded by local residents, who believed that they were safe because cyclone tracks in this area historically had changed course and headed north. Although it cannot be attributed to climate change, the disaster in Cagayan de Oro is emblematic of the risks associated with climate change, wherein populations are ill-prepared for more intense, frequent, or shifted hazards, like Sendong's intense rains, associated flooding, and unusual storm track. The experience in Sendong is still fresh in the minds of decision-makers and citizens alike throughout the Philippines, and it presents a good opportunity to capitalize on this attention to improve short-term disaster preparedness, increase understanding of the risks, and improve overall resiliency to medium-term climate change impacts throughout the Philippines.

Storm damage in 2010 after typhoon Megi hits the Philippines.

Photo credit: USAID.

Readers may notice that there is a significant overlap between addressing vulnerability to climate variability (i.e., current climate) and vulnerability to climate change (i.e., future climate). Many adaptation measures can reduce vulnerability to both current and future climates. It is also the case that many development initiatives have substantial vulnerability to current climate, such as droughts, floods, and cyclones. Climate change may already be increasing those vulnerabilities and will further increase those vulnerabilities in the future. Consequently, this annex addresses "climate vulnerability," which includes vulnerability to both climate variability and climate change. The phrase "climate impacts" is used throughout this document to refer both to the impacts of current climate variability as well as projected climate change.

Many of the actions envisioned in the discussions that follow are what are called "no-regrets" options (i.e., they can be justified based on current climate alone and are further justified when climate change is considered). Such no-regrets options can be sufficient to adapt to climate impacts in coming years and

decades. However, over the longer-term, very significant changes in climate are expected. These changes in climate may require much more substantial adaptation actions than no-regrets options alone. In planning for climate impacts, it is very important to keep in mind and allow for significant adaptation actions to be planned for and implemented, especially over longer timeframes.

1.2 WHAT DOES CLIMATE CHANGE MEAN FOR WATER RESOURCES SYSTEMS?

Significant scientific effort has gone into understanding the implications of climate change for water resources systems. Collectively, most studies suggest that we need to be concerned about three main issues, as succinctly stated by the Intergovernmental Panel on Climate Change (IPCC): "The challenges related to freshwater are: having too much water, having too little water, and having too much pollution" (Bates et al., 2008). This annex focuses on freshwater resources. Please refer to the coastal annex to the USAID (2014a) climate-resilient development framework for a detailed discussion of the implications of climate change on coastal and marine ecosystems, sea level rise effects on coastal settlements, and other non-freshwater resources issues.

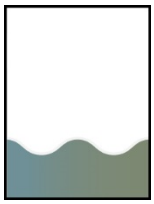
TOO MUCH WATER

In some locations total annual precipitation is projected to increase, but heavy precipitation events are anticipated to increase even where total precipitation declines. More extreme precipitation can lead to more frequent or intense flooding events that threaten human and natural systems associated with or located adjacent to water resources.

TOO LITTLE WATER

Climate change will mean higher temperatures and changes in precipitation patterns. Higher temperatures will lead to greater evaporation of water supplies from lakes, reservoirs, and cisterns, as well as greater demands for irrigation and human consumptive-use water. Precipitation is also projected to decrease in many locations. Even in locations where overall precipitation increases, it may come as fewer, but more intense precipitation events with longer dry periods or even prolonged droughts. Seasonal shifts or intensified dry periods can lead to water shortages, less groundwater infiltration, and a greater reliance on seasonal and inter-annual storage capacity. Some areas are experiencing changes in the length or timing of rainy seasons. Such seasonal shifts are often obscured in aggregated annual data, but may have significant consequences if rainy seasons are delayed.

DEGRADED WATER



Water quality can be degraded by climate change for a number of reasons. Where surface water quantity is reduced, there will be less dilution of effluent, higher contaminant levels, and a higher probability of disease outbreaks. Sea level rise will increase the salinity of coastal aquifers and exacerbate their over-depletion, leading to the compromise of freshwater resources that could otherwise be used for human consumption. More intense storms may lead to increased runoff and flooding that can affect water quality by transporting nonpoint source pollutants, increasing the sediment load in drinking water sources, causing sewage overflows, and creating conditions for more exposure to waterborne pathogens. Furthermore, higher temperatures, higher peak flows during the rainy season, and flooding events can all exacerbate diarrheal disease tied to poor hygiene and lack of access to safe water. Warmer temperatures can also lead to harmful algal blooms that produce toxins that lead to human

disease.[1] Higher temperatures can lead to lower dissolved oxygen levels, which could harm aquatic ecosystems and reduce the ecosystem services they provide.

The scientific literature on climate change and water (e.g., Bates et al., 2008; Field et al., 2014) suggests that many of these changes are already happening. Temperatures and sea levels are increasing, mountain glaciers and snowpack are melting, and precipitation patterns in many locations are changing. We also know from records of prehistoric climate, such as tree rings and lake sediments, that the climate of even just a few hundred years ago in many locations experienced more intense and long-lasting extreme events such as drought than has been recorded over the last 50 to 100 years, providing a historical analog for projections of future changes. Furthermore, a large body of scientific evidence indicates that the climate impacts experienced so far are only an indication of what we can expect to happen in the future due to "committed climate change" from greenhouse gas (GHG) emissions to date and as emissions continue to rise.

1.3 WHY SHOULD I READ THIS ANNEX?

The consequences of climate impacts are going to be important for many people working on water resources. In short, if you have any role in managing, planning for, funding, or operating a water resource, understanding the implications of climate vulnerability is important for long-term success in achieving your objectives. Climate variability and change have real impacts on water resources that can be problematic themselves, but that can also exacerbate existing non-climate stressors such as deforestation, population migration and growth, increasing agricultural water demand, depletion of fossil aquifers, and more.

Such climate impacts can put water sector development goals such as increasing access to potable water, increasing agricultural productivity, improving drinking water quality, and reducing vulnerability to drought at risk. These development goals should remain the primary guide in making development decisions. To make the best use of limited resources to support development over the long-term, climate impacts need to be incorporated as an additional consideration when assessing and selecting among development alternatives. This annex builds on the USAID (2014b) climate-resilient development framework to ensure the systematic inclusion of climate considerations in development decision-making – a "development-first" approach to considering climate vulnerability.

Photo credit: Jason Vogel.

1. For example, gastrointestinal, respiratory, and neurological illnesses such as ciguatera through the consumption of fish.

Climate impacts will affect water-related development initiatives, but especially infrastructure, institutional, and resource management initiatives with a lifetime greater than one decade. Longer-lived projects will tend to have the greatest exposure to climate change. As a result, a variety of what has been seen as standard operating procedures could be threatened by changing climate conditions, and water systems must be prepared for such changes over the coming decades. Even projects intended for shorter-term results (such as some water, sanitation, and hygiene programs) may influence longer-term practices and approaches, so it is important to consider the implications of a changing climate to ensure sustained success.

Planners for water systems need to consider climate vulnerability as a fundamental driver that will determine water system success. In many cases, managers, planners, and operators are already addressing climate variability, but new and different actions may be necessary to prepare for even greater changes in the future. Whether you are in a policymaking, funding, or design and implementation position, it is critical that you address climate vulnerability by using a sound methodology to consider climate impacts in the context of development. USAID recommends the framework described in *Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change* (USAID, 2014b). If climate impacts are not considered, we can expect the degradation over time of many existing and planned water management systems in their ability to provide safe and reliable water supplies or to protect people and property from flooding.

Many investments in development are connected directly or indirectly to water resources. Nevertheless, a significant gap exists in our ability to manage freshwater systems sustainably over operational lifetimes that sometimes span decades or centuries. This issue is manifested in many developed world infrastructures and institutions that no longer match their ambient climate, leading to significant economic and ecological impacts. Investments with such hidden economic and ecological costs put developing economies at risk, and may undermine the natural capital that supports livelihoods. According to the GIZ,[2] "Climate impacts are affecting the success of long-term development efforts. Development programmes therefore need to take climate risks into account in order to guarantee project sustainability" (GIZ, 2011). This annex is designed to provide water managers, development practitioners, and others with a succinct, but comprehensive understanding of the challenges posed by climate change.

This annex provides useful information to promote climate-resilient development at the project level in the water sector. Additionally, this annex assists in updating sector strategies, such as national water resources strategies, basin management plans, municipal water management plans, national agriculture plans, health management plans, and integrated water resources management (IWRM) plans.[3] Furthermore, this annex assists in bringing climate vulnerability to bear on national development programs, such as sustainable development, food security, or poverty reduction programs that will be affected by changes in water resources. We do not provide an exhaustive discussion of the science behind climate impacts on water resources, but we do synthesize and condense the relevant science to make it useful for the non-specialist. For those who are interested in more detail on the science of water and climate change, we recommend starting with the IPCC *Climate Change and Water* report (Bates et al., 2008) and the relevant chapters in the IPCC Working Group II Fifth Assessment Report (Field et al., 2014) as comprehensive and authoritative resources.

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2. GIZ is the German abbreviation for Deutsche Gesellschaft für Internationale Zusammenarbeit, the German national development aid organization. GIZ was developed by combining the Deutsche Gesellschaft für Technishe Zusammenarbeit (GTZ) with a few other government entities.

3. IWRM promotes coordinated development and management of water, land, and related resources in order to maximize economic, social, and environmental welfare.

1.4 HOW DOES THIS ANNEX RELATE TO THE CLIMATE-RESILIENT DEVELOPMENT FRAMEWORK?

The USAID (2014b) climate-resilient development framework is designed to help development planners and practitioners integrate climate concerns into strategies, programs, and projects. The framework provides a structured step-by-step process for incorporating consideration of climate impacts into existing decision processes. The framework builds upon a conventional project cycle management framework, which is used by development institutions to manage their projects and programs. This framework is illustrated in Exhibit 1 and consists of five stages: (1) scope, (2) assess, (3) design, (4) implement and manage, and (5) evaluate and adjust. This water annex provides interested practitioners and policymakers with more specific advice tailored to the water resources sector.[4] In an important sense, this annex provides the substance necessary to begin to use the process outlined in *Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change* (USAID, 2014b) within the water resources sector. But even the information in this water annex is generalized. Any specific strategy-, program-, or project-level intervention will require even further specification than can be provided here. For a site-specific application of the water annex, please refer to the *An Assessment of Water Security, Development, and Climate Change in Iloilo, Philippines and the Tigum-Aganan Watershed* (USAID, 2013).

The water annex focuses on a limited subset of the tasks in the scope, assess, and design stages of the framework. The scope tasks highlighted in this water annex include *framing the planning process* and *identifying climate and non-climate stressors*. The assess task highlighted in this water annex is *exposure assessment*. The design task highlighted in this document focuses on *identifying adaptation actions* to increase the resilience of the water sector to climate stressors. To fully understand the proposed framework and approach, we recommend reading *Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change* (USAID, 2014b).

4. In addition to the climate-resilient development framework document and this water annex, USAID is producing other companion annexes that address critical issues and sectors. The coastal annex, like the water annex, is a sector-specific application of the climate-resilient development framework. The vulnerability assessment annex focuses in greater detail on how to conduct a vulnerability assessment. The evaluating adaptation options annex elaborates on the design stage of the framework. The governance annex and marginal populations annex were developed because these two issues are considered critical for climate-resilient development. The climate change and conflict annex considers the relationship between climate and non-climate stressors that can lead to or exacerbate conflict and security challenges.

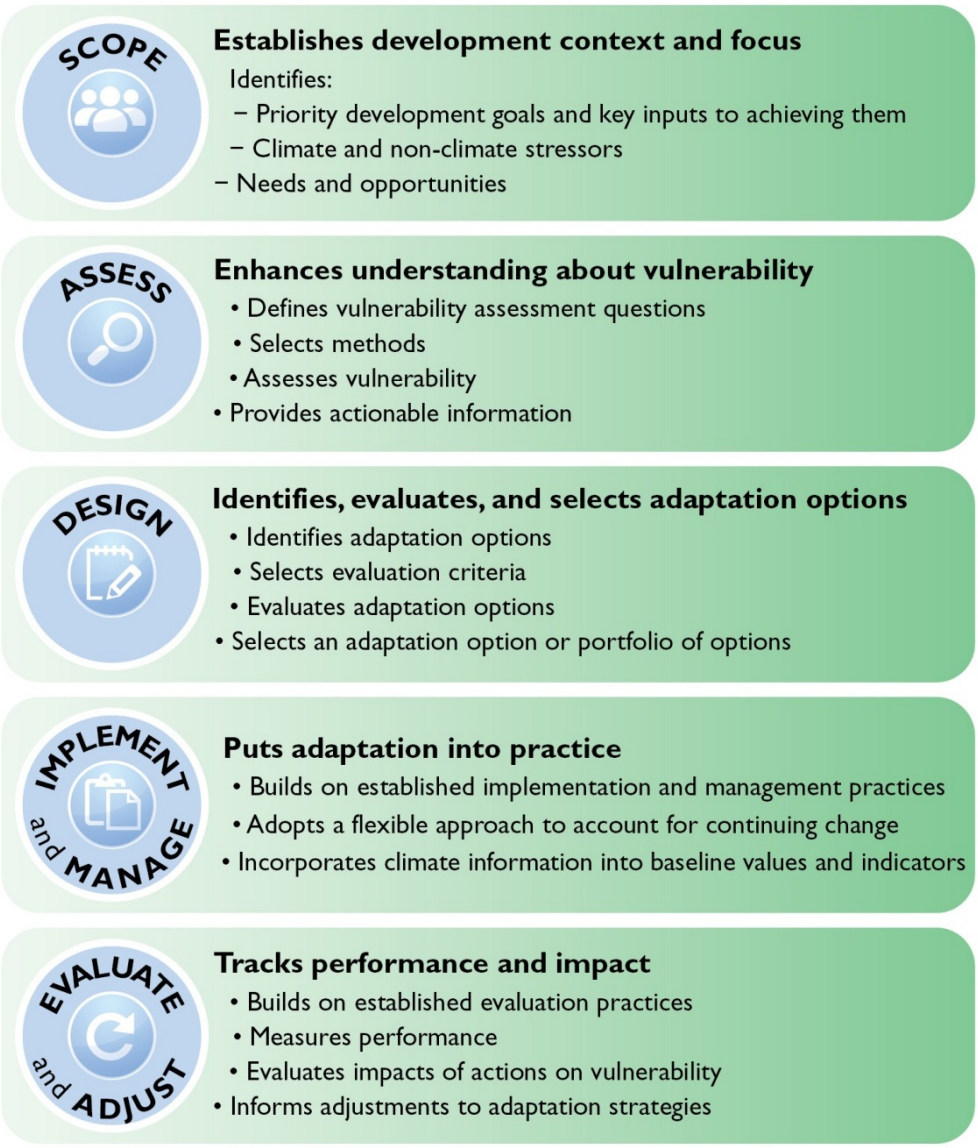


EXHIBIT 1. USAID'S CLIMATE-RESILIENT DEVELOPMENT FRAMEWORK.

2. SECTORS AFFECTED BY WATER RESOURCES

WATER SECURITY GOES MAINSTREAM

"The difficulties start with the sheer number of people using the stuff. When, 60 years ago, the world's population was about 2.5 billion, worries about water supply affected relatively few people. Both drought and hunger existed, as they have throughout history, but most people could be fed without irrigated farming. Then the green revolution, in an inspired combination of new crop breeds, fertilizers and water, made possible a huge rise in the population. The number of people on Earth rose to 6 billion in 2000, nearly 7 billion today, and is heading for 9 billion in 2050. The area under irrigation has doubled and the amount of water drawn for farming has tripled. The proportion of people living in countries chronically short of water, which stood at 8% (500 million) at the turn of the 21st century, is set to rise to 45% (4 billion) by 2050. And already 1 billion people go to bed hungry each night, partly for lack of water to grow food…. Climate change threatens to make the problem worse" (Grimond, 2010).

There are numerous ways to subdivide water issues – an important task in order to explore the many facets of this critical resource. The sectors or topics described below are not meant as mutually exclusive and exhaustive categories, but rather as a proposed common language to enable a more nuanced discussion of climate vulnerability. These categories can also assist in defining water-related development objectives. We have adapted these categories from the IPCC *Climate Change and Water* technical paper (Bates et al., 2008):

- Water supply and sanitation
- Agriculture, food security, land use, and forestry
- Human health
- Settlements and infrastructure
- Ecosystems and biodiversity
- Energy

IWRM can promote coordinated development and management of water, land, and related resources across all of these sectors in order to maximize economic, social, and environmental welfare. We mention this concept here because in subdividing water resources into the sectors or topics above, we believe it is

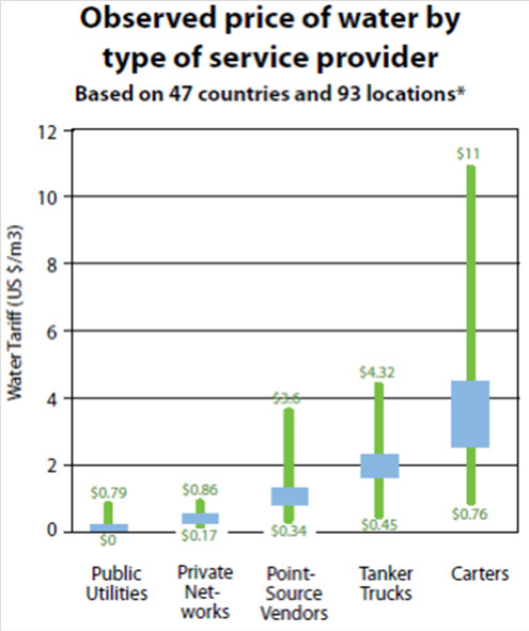
important to emphasize that remaining aware of the linkages across sectors and the broader context may provide more efficient or preferable alternatives to sustain water resources (e.g., USAID, 2008). IWRM focuses on the many competing demands for water (e.g., urban, agriculture, industrial, environmental) to coordinate water resources management within and across sectors, levels of government, water basins, and more. IWRM posits that when such coordination is possible, the vertical and horizontal integration of water resources can provide a more equitable, efficient, and sustainable allocation of limited water resources. For more information on IWRM, see the Introduction to Appendix A in this document.

2.1 WATER SUPPLY AND SANITATION

Water is not always available when and where people need it. This has led to the development of reservoirs, aqueducts, ditches, wells, and other means to ensure that water is available to address both intra- and inter-annual water shortages, and in locations distant from rivers and lakes. Water quality and sanitation have become increasingly important as we have realized the need for suitable treatment of water supplies and wastewater to protect human health and the environment. One United Nations Millennium Development Goal (MDG) has a target to "Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" (UN, 2012). Although the MDG for access to safe water has been achieved, there are still 783 million people who do not have access to improved sources of water, and about 2.5 billion people do not have access to any form of improved sanitation services (WHO, 2012).

WATER PRICING FOR PIPED/NON-PIPED WATER

The price of water and/or its conveyance and delivery in developing countries varies considerably according to the type of service provider. Piped water provided by public utilities is typically the least expensive (see graph at right) in part because of favorable economies of scale, but also because prices do not typically reflect the full costs of investment, rehabilitation, and operations and maintenance (O&M). The most expensive water is provided by point-source vendors, tanker trucks, and hand-cart water delivery. The poor in developing countries pay considerably more in absolute terms for water than those better off and as a percentage of household income. Illustratively, in Manila, Philippines, the poor pay 9 times the tariff for the better off; in Lagos, 10 times; in Cairo, Egypt, 40 times; and in Jakarta, Indonesia, 60 times (Hutton and Haller, 2004). Climate change may have significant impacts on the distributional aspects of water and its costs, particularly as it exacerbates current and future development challenges.



Source: Kariuki and Schwartz, 2005.

2.2 AGRICULTURE, FOOD SECURITY, LAND USE, AND FORESTRY

While most agricultural land is not irrigated, irrigated agriculture is a major source of the world's food supply and, in many locations, provides the majority of food (World Bank, 2012). In addition, irrigated agriculture accounts for 70% of freshwater resources consumption worldwide (Pimentel et al., 2004). Freshwater aquaculture is also a major source of food in some regions (marine fisheries are discussed in the coastal annex (USAID, 2014a). Current climate variability has significant effects on agriculture and aquaculture. These effects are most severe and immediate for rainfed agriculture, but also pose significant threats for irrigated agriculture and aquaculture. For example, climate can affect the availability of water for irrigated agriculture, the frequency and intensity of agricultural pest outbreaks, the prevalence of weeds and invasive species, crop productivity, the temperature of aquaculture ponds, and water availability for aquaculture, among other considerations. This is because critical physical and ecological processes associated with each of these attributes are sensitive to climate, including average, seasonal, and extreme temperatures; precipitation amount and timing; and patterns and intensities of drought.

VIRTUAL WATER

Water stress is a pervasive problem in developing countries and a key constraint in the pursuit of economic, food security, and health goals (see Brown and Matlock, 2011, for a review of water stress concepts, indicators, and global trends). Water stress is expected to be exacerbated by population and economic growth as well as climate change. One option for alleviating water stress relates to the concept of "virtual" water and its role in international trade. The concept of virtual water was coined by Tony Allan in the early 1990s and is defined as the water used in the production process of an agricultural or industrial product (Hoekstra, 2003). For crops and livestock, the production of 1 kg of food can require 1,000 + kg of water. For water-stressed countries, food and industrial imports of products requiring large inputs of water is an option for meeting increased demands for water that may be significantly less expensive than developing new sources of water.

USAID water project for coffee stations in Burundi.

Photo credit: DAI.

2.3 HUMAN HEALTH

According to the World Health Organization (WHO, 2012), in the year 2010, 11% of the global population (783 million people) did not have access to safe drinking water (defined as the availability of at least 20 L of water per person per day from an improved water source within a distance of 1 km). Approximately two-thirds of these people are in Asia. In sub-Saharan Africa, approximately 39% of the population did not have safe drinking water access (WHO, 2012). Beyond direct health impacts, there are cascading impacts from lack of access to safe water. Poor urban households can spend a large portion of their available time and money obtaining drinking water, preventing those resources from being used for other purposes which could improve these households' quality of life and health outcomes. In rural areas, some households, and especially

women and children, spend large amounts of time obtaining potable water from distant locations, preventing the most vulnerable from using their time in educationally or economically productive ways which could also improve their quality of life and reduce human health risks. With time and resource constraints, many people resort to unsafe, but more affordable water options.

Furthermore, 2.5 billion people worldwide are without access to improved sanitation (WHO, 2012). The WHO estimates the total burden of disease due to unsafe water, inadequate sanitation, and poor hygiene is 1.6 million deaths per year (WHO, 2012). For example, poor water quality contributed to a recent cholera outbreak of 470,000 cases and 6,631 deaths in Haiti (CDC, 2011). Childhood mortality and morbidity due to diarrheal disease in low-income countries, especially sub-Saharan Africa, remains extremely high despite public health, sanitation, and hygiene initiatives.

2.4 SETTLEMENTS AND INFRASTRUCTURE

Protection against the risks of flooding and drought are fundamental considerations that have permeated infrastructure design and water management practices throughout developed as well as developing countries. Year-to-year climate variability has necessitated specific developments, especially concerning floods and droughts. For example, reservoirs have been developed along major waterways throughout the world to provide water supply during periods of limited precipitation and low surface flows, and to control flooding in major river systems. Seawalls, levees, and other infrastructures have been built to provide protection against flooding. Typically the design of such infrastructures is grounded in an analysis of historical climate based on observed extremes and perhaps an additional safety factor.

2.5 ECOSYSTEMS AND BIODIVERSITY

Aquatic and riparian ecosystems have evolved to survive based on natural flow and availability of water resources. Human use and alteration of water supplies have clearly affected such ecosystems around the world through changes in water quality, quantity, and flows (e.g., by damming rivers). Increasing human consumption of surface sources to meet increased human consumptive use, irrigation, industrial, and other needs has affected ecosystems by changing the amount and quality of water that can meet ecosystem needs. Importantly, many of these ecosystems also provide a multitude of services for human society, including food sources, maintenance of high-quality water, natural filtration of lower-quality water, flood prevention and abatement, groundwater infiltration, and more. Climate impacts will affect ecosystems and biodiversity through changes in water temperature, flows, and quality – in both natural and managed water bodies.

2.6 ENERGY

Energy and water are closely linked. The extraction, distribution, and treatment of water require the use of energy (Haas, 2009). For example, irrigation, inter-basin transfers, desalination, source water treatment, wastewater treatment, distribution of drinking water, and collection of wastewater and stormwater all require large inputs of power. Energy is also a key input in the fabrication and construction of water infrastructure. Furthermore, water is the essential input in the production of hydro-electrical power. Finally, it is also needed for cooling in thermo-electrical power generation. Demands for water and energy as a result of population and economic growth are expected to increase significantly and in parallel in coming decades.

The United Nations World Water Assessment Programme projects that demand for water in developing countries could increase by 50% by 2030 due to irrigated agriculture expansion, population growth, economic development needs, and changes in climate (UNESCO, 2012b). Global energy consumption is projected by the International Energy Agency to increase by 50% between 2007 and 2035, with non-Organisation for

Economic Co-operation and Development countries accounting for 84% of this growth mainly due to population growth and rising living standards (UNESCO, 2012a). These trends highlight the challenges of achieving sustainable development of energy and water resources as demand for both water and energy grow due to population increases and economic development.

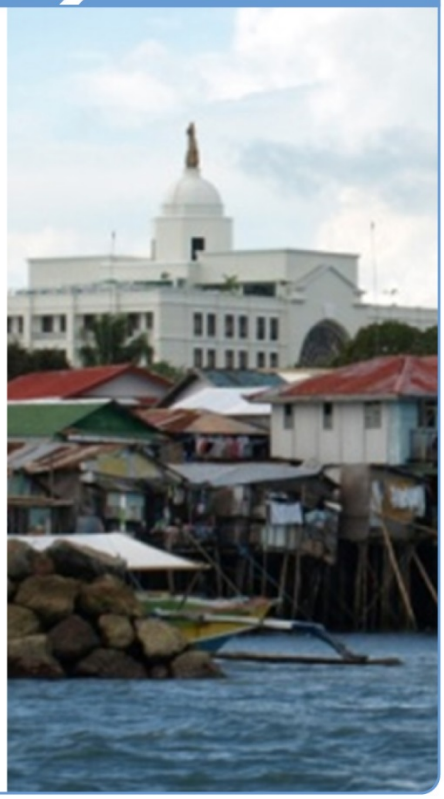
These increasing demands will be amplified as a result of projected climate changes: higher temperature will increase evaporation rates for surface water, increase agricultural water demand due to higher evapotranspiration rates, increase peak electricity demand for air conditioning, reduce the efficiency of thermoelectric cooling, and more. Large shifts in rainfall patterns could drive new costly energy-intensive investments to maintain water supply and quality, reduce flows at hydroelectric facilities, and require energy-intensive investments in water treatment infrastructure. Sea level rise could threaten coastal aquifers and require the development of new water sources or treatment options. Changing seasonal flows due to changes to snowpack and glaciers could affect downstream electricity generation systems. If energy and water are not considered in an integrative fashion, adaptations to climate change for one may lead to non-optimal solutions or outright negative consequences for the other.

Development goals: The Iloilo case study example below provides a concrete example of identifying development goals and their relationship to the water sector – including issues of water supply (Section 2.1), sanitation (Section 2.1), and agriculture (Section 2.2). For the full Iloilo, Philippines case study, please see the USAID (2013) document *An Assessment of Water Security, Development, and Climate Change in Iloilo, Philippines and the Tigum-Aganan Watershed.*

Iloilo, Philippines — DEVELOPMENT GOALS

Municipal, provincial, and regional stakeholders expressed a consistent set of development objectives for the metro Iloilo area, including promoting tourism, spurring commercial development, and expanding local agriculture. Initial efforts on tourism, such as a waterfront walkway, have been hampered by water issues such as poor water quality in the Iloilo River. The Iloilo Business Park, located on the site of the old airport, is in initial construction stages, despite some concern expressed by the investors over both reliability and the cost of water and electricity supplies. Expanding agricultural production is a key objective of the recently approved Jalaur Dam project, but there are no plans yet for transporting and treating the fraction of this water intended for municipal use in metro Iloilo. Almost all stakeholders interviewed identified inadequate water supply and high energy costs as the two greatest constraints on progress toward the priority development objectives of metro Iloilo and the rural areas of the Tigum-Aganan Watershed. The consensus among the vast majority of community members was that inadequate water supply is the number one constraint and priority.

Note: Initial drafts of this water annex were used to guide a case study of water security, development, and climate change in Iloilo, Philippines in 2012. On-the-ground experience from that case study will be used throughout this annex to illustrate important points.



3. CLIMATE STRESSORS ON WATER RESOURCES SYSTEMS

Climate affects water resources both as intra- and inter-annual variability and as longer-term changes in precipitation, temperature, and other climate variables. Water managers have sought to address variability around mean conditions for much of human history. But climate change adds a new dimension to water resources management. Instead of managing a system for average conditions within a historically defined range of variability, both the average conditions and the range of variability are likely to change over time. The best available science indicates that the climate is already changing. It also projects a substantially altered future climate due to the lag between emissions of GHGs from the recent past and their full impacts on the climate system in the future. We briefly discuss climate variability below as the starting point from where water managers can explore the implications of climate change. The remainder of this section then deals with the impacts of climate change on water resources.

The water sector has a history of trying to manage climate variability in conjunction with the non-climate stressors discussed in Section 4. Climate conditions such as temperature or precipitation can vary, sometimes dramatically, from expected average conditions. Because of this natural variability in climate, it is quite common for the water sector to prepare for uncertainties such as drought years, flooding events, delays in the onset of the rainy season, and other conditions that are perhaps rare, but anticipated. It is worth considering both intra- and inter-annual variability when thinking about climate-resilient development because the methods of dealing with each can be quite different. Despite experience in managing natural climate variability, however, some developing countries have significant development and infrastructure deficits that prevent them from adequately addressing even these well-known and predictable risks.

The consequences of climate change for water resources are likely to be profound (e.g., Bates et al., 2008). Global average temperatures are projected to increase from 1.1°C to 6.4°C over the 21st century (with local extremes of increased variability in some places).[5] This temperature change alone would have profound effects on water resources through impacts such as increased evapotranspiration, melting glaciers, warmer water temperatures, and more frequent hot extremes and heat waves. A number of additional projected changes to water resources are described below. Although we do not emphasize the point in each section

5. This includes various scenarios of economic development, population growth, consequent GHG emissions, as well as scientific uncertainties.

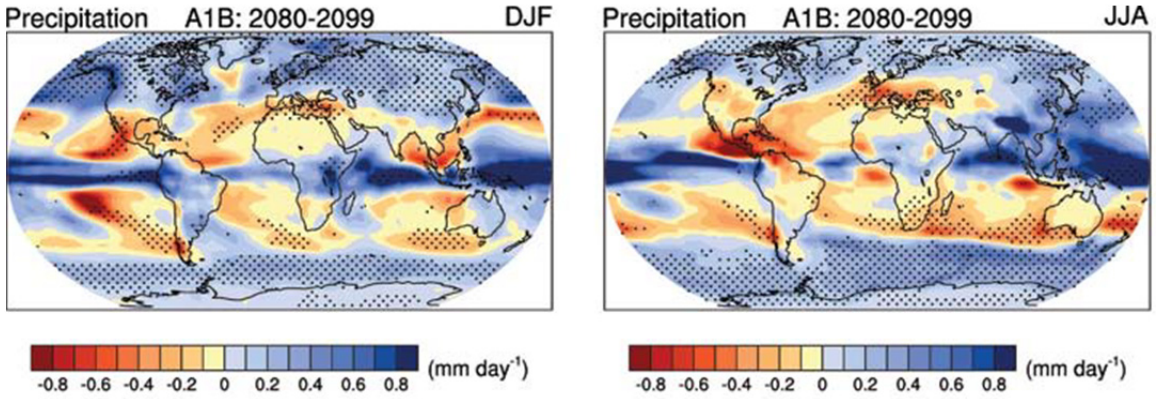
below, it should be noted that projected climate impacts on water resources are inherently uncertain because of a number of important factors, including uncertainty about how much climate will change and the difficulty of modeling how precipitation will change at the local scale. Despite these uncertainties, extensive scientific work has been done to understand the potential climate impacts on water resources. What we describe below is drawn largely from a state-of-the-science report by the IPCC (Bates et al., 2008) and other authoritative resources (e.g., Church et al., 2013; Field et al., 2014).

This section addresses the following climate stressors:

- Average and extreme precipitation
- Snow and land ice
- Sea level
- Evapotranspiration
- Soil moisture
- Runoff and river discharge
- Patterns of large-scale variability

3.1 AVERAGE AND EXTREME PRECIPITATION

Global climate models all show an increase in global average water vapor, evaporation, and precipitation over the 21st century. This average disguises very different projections for regional precipitation change. At the regional level, climate models generally project precipitation increases at high latitudes, over the tropical oceans, and in areas with monsoon regimes (e.g., south Asian monsoon in June through August, Australian monsoon in December through February). In contrast, widespread decreases in precipitation are projected in summertime for most mid-latitude locations (e.g., Central America, the Mediterranean, North Africa), although models project increased precipitation in East Asia (see Exhibit 2). In addition, local extremes of increased variability may be more significant than these changes to global or regional averages.



Yellow, orange, and red indicate areas of projected decreased precipitation while shades of blue represent areas of projected increased precipitation. Stippling represents areas of high model agreement. DJF is December/January/February and JJA is June/July/August. This exhibit demonstrates projected patterns of precipitation averaged across 15 models, but such projections have a high level of uncertainty as indicated by the areas without stippling. Note that considering additional socioeconomic scenarios besides A1B would further increase uncertainty.

EXHIBIT 2. IPCC AVERAGE PROJECTIONS (USING 15 MODELS) FOR WINTER AND SUMMER PRECIPITATION CHANGES FOR THE PERIOD 2080–2099 RELATIVE TO 1980–1999.

According to Bates et al. (2008), "Increases in annual precipitation exceeding 20% occur in most high latitudes, as well as in eastern Africa, the northern part of Central Asia and the equatorial Pacific Ocean. Substantial decreases of up to 20% occur in the Mediterranean and Caribbean regions and on the sub-tropical western coasts of each continent." Furthermore, even at the regional level, there may be important changes in the seasonality of precipitation. It is particularly important to consider the timing of precipitation – such as changes in the onset of the rainy season – which can be obscured in average annual data.

The IPCC has determined that it is very likely that heavy precipitation events will become more frequent. In most areas that are expected to get wetter on average, extreme precipitation is expected to increase at a faster rate than total precipitation increases. Even in areas that are projected to get dryer on average, precipitation is projected to be concentrated in more intense events with longer dry periods in between. Consequently, intense and heavy episodic rainfall events with high runoff amounts may reduce soil moisture absorption while also increasing flood risk. The IPCC has also determined that it is likely that future tropical cyclones will become more intense as sea surface temperatures increase and the tropics expand. More intense tropical cyclones tend to have more precipitation (and stronger winds).

3.2 SNOW AND LAND ICE

Due to increasing temperature, land ice, glaciers, and snow cover are generally projected to decrease, although local impacts will vary. In general, snow accumulation is projected to begin later and melting is projected to begin sooner, shortening the snow accumulation season. Furthermore, glaciers are projected to lose mass because summer melting will predominate, even where winter precipitation is projected to increase. In many areas, glaciers may disappear completely. Note that some places could have higher snow amounts during the shorter cold season, offsetting increased melting from higher temperatures. This is not expected to happen widely. Reduced snow and ice can lead to lower recharge and retention of water resources.

3.3 SEA LEVEL

Sea level rise will pose many challenges for management of coastal resources and many sectors within coastal zones. Here we limit the discussion to the implications of sea level rise for groundwater intrusion, freshwater lenses, and other freshwater resources issues. Please refer to the *Climate Change and Coastal Zones: An Annex to the USAID Climate-Resilient Development Framework* (USAID, 2014a) for a detailed discussion of the implications of sea level rise on settlements, transportation systems, coastal habitats, marine ecosystems, and other non-freshwater resources issues. Globally, sea level is projected to rise over the course of the next century, although the exact amount is uncertain and local impacts will vary greatly. Estimates range from a few tenths of a meter to as much as two meters by 2100. Higher sea levels can lead to greater salinization of near-ocean, freshwater bodies through inundation or storm surge, saltwater intrusion into near ocean groundwater aquifers, and salinization of the freshwater lenses that underlie many small islands.

3.4 EVAPOTRANSPIRATION

Evaporation is projected to increase almost everywhere due to warming air temperatures. Over water bodies (e.g., oceans), this means greater evaporation rates. Over land, the situation can be more spatially varied and affected by changes in precipitation and the availability of water in soils, water bodies, and vegetation. This can impact the water balance of runoff, soil moisture, lake and reservoir water levels, the groundwater table, and the salinization of shallow lakes and aquifers. Transpiration (i.e., the evaporation of water due to the biological activity of plants) can also be affected by changing carbon dioxide levels, which can reduce water demand by crops and affect crop productivity. In many cases plant growth will be reduced by a drier climate. For example, research on rain-fed African maize has shown that for every day above 30°C during the growing

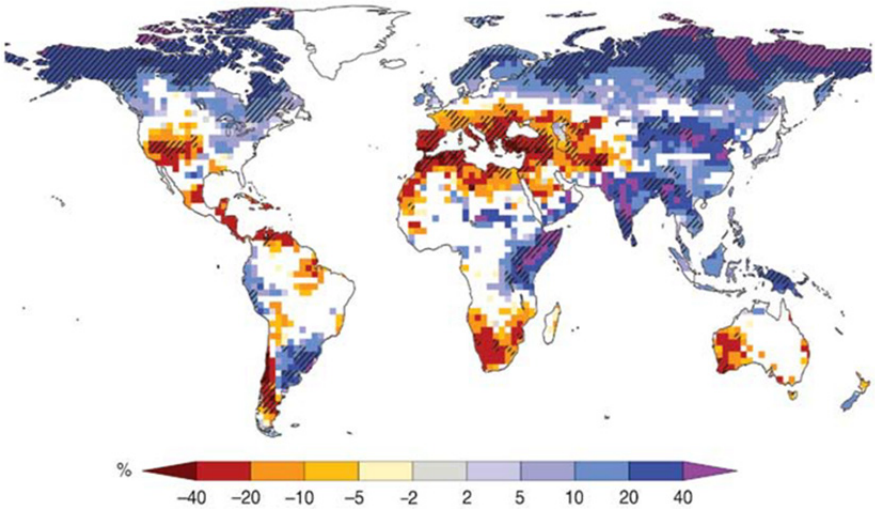
season, there was a decrease in yields of approximately 1–2%, depending upon the precipitation levels (Lobell et al., 2011).

3.5 SOIL MOISTURE

Changes in soil moisture are determined by both changes in precipitation and evaporation. The amount of area considered very dry has doubled since 1970 (Dai et al., 2004). Projections of annual mean soil moisture content in the 21st century indicate decreases in the subtropics, the Mediterranean, and at high latitudes. Soil moisture is expected to increase in East Africa, Central Asia, and other regions with projected increases in precipitation. Similar patterns emerge for seasonal soil moisture content as well. While the magnitude of such changes remains uncertain, the projected direction of change is consistent in many of these regions.

3.6 RUNOFF AND RIVER DISCHARGE

A number of global studies project that future runoff is likely to increase at high latitudes and the wet tropics but to decrease in mid-latitudes and some parts of the dry tropics. Some of these changes can be quite large and tend to correlate both with areas of increasing (e.g., Southeast Asia) and decreasing (e.g., the Mediterranean) precipitation. Projections indicate increases in flows for high-latitude rivers, but decreases for major rivers in the Middle East, Europe, and Central America (see Exhibit 3). Studies also project an increase in the seasonality of flows, with higher flows in the wet season and lower flows in the dry season, particularly for regions that do not rely on snowmelt. Note that even in areas with projected increases in runoff, some seasonal effect may still have a significant impact on water resources, such as the combination of increased wet season runoff with decreased dry season runoff – potentially resulting in severe flooding and sedimentation. For rivers draining glaciated regions, such as the Asian high mountain regions and the South American Andes, increases in river flows, glacial lake size, and groundwater recharge are projected in the near-term as glacial retreat accelerates, followed by decreases in flows as the glaciers recede or disappear entirely (Bates et al., 2008).



Yellow, orange, and red indicate areas of projected decreased runoff while shades of blue and purple represent areas of projected increased runoff. White areas indicate that less than two-thirds of the models agree on the sign of change and hatched areas indicate more than 90% of the models agree on the sign of change (Milly et al., 2005).

EXHIBIT 3. AVERAGE PROJECTED CHANGES IN ANNUAL RUNOFF (USING 12 MODELS) FOR THE PERIOD 2090–2099 RELATIVE TO 1980–1999.

3.7 PATTERNS OF LARGE-SCALE VARIABILITY

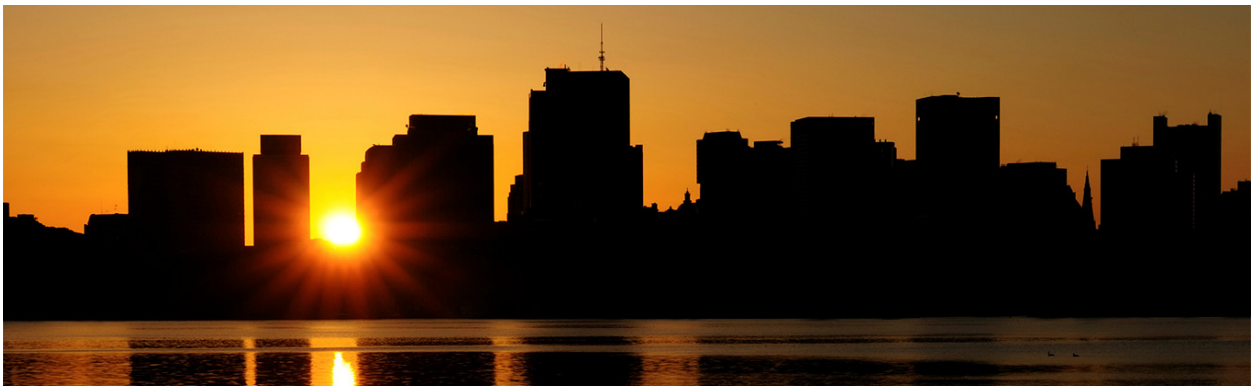
In addition to direct effects on temperature and precipitation, climate change is expected to alter storm tracks, ocean temperatures, and inter-annual temperature and precipitation variability. For example, current research has detected a poleward shift in storm tracks outside the tropics in the southern hemisphere. Such changes are anticipated in the northern hemisphere as well. Pacific precipitation regimes are also likely to shift eastward as the equatorial Pacific warms differentially. Changes in regional temperature and precipitation patterns such as the El Niño Southern Oscillation are also possible. These changes are significant because they indicate that climate change will not manifest simply as a few degrees warmer than normal. Instead, significant changes in climate variability, precipitation, dry season length, and storm tracks may define a new normal that looks dramatically different from past climate change.

Climate stressors: The Iloilo case study example below provides a concrete example of identifying climate stressors and their relationship to the water sector – including increased temperatures, changes in timing of the rainy season (Section 3.7), and typhoons (Section 3.1). For the full Iloilo, Philippines case study, please see the USAID (2013) document *An Assessment of Water Security, Development, and Climate Change in Iloilo, Philippines and the Tigum-Aganan Watershed.*

Iloilo, Philippines — CLIMATE STRESSORS

Observations across the Philippines indicate that minimum night time temperatures have increased by 1.0°C and maximum daytime temperatures have increased by 0.36°C over the last 60 years (1951–2009). This Philippine Atmospheric, Geophysical, & Astronomical Services Administration (PAGASA) projects that average temperatures in Iloilo will rise just over 1°C by about 2025 and about 2 to 2.5°C by 2050. Furthermore, water security in the Philippines is affected by the dry season in March, April, and May, when agricultural and residential water deliveries are often restricted. A potential lengthening of the dry season would exacerbate these impacts. As an example, it was reported that during the 2010 El Niño event, the Iloilo area went eight months without rain, restricting water deliveries and reducing coverage to only approximately 5% of the population in the service area. Typhoons are quite common in the Iloilo area and cause extensive flooding, impair water quality, and harm public health. One likely outcome of climate change is that typhoons will become more intense. However, according to PAGASA, there is too much variability to identify any statistically significant trends in tropical cyclone occurrence or intensity in the historical record.

4. NON-CLIMATE STRESSORS ON WATER RESOURCES SYSTEMS



Water resources in many areas are already stressed from non-climate factors. Non-climate stressors have led to water shortages, agriculture and forestry stresses, water quality and human health issues, settlement and infrastructure vulnerability, and ecosystem impacts as described in Section 2. We describe some of these existing non-climate stressors here because they are significant determinants of the sustainability of water resources. In some cases climate impacts may simply exacerbate existing non-climate stressors. In other cases, these existing stressors need to be proactively managed for the water sector to withstand increased climate impacts. This section addresses non-climate stressors including:

- Population growth
- Urban development and infrastructure needs
- Pollution and environmental degradation
- Groundwater depletion
- Inappropriate government policies and practices
- Poor resource governance
- Poor watershed management
- Insufficient planning, permitting, and enforcement

4.1 POPULATION GROWTH

According to the United Nations Population Division, the world population is projected to increase from 6.9 billion in mid-2011 to 9.3 billion in 2050, and reach 10.1 billion by 2100 (UN, 2011). Most of this population growth is anticipated to occur in developing countries, especially in Africa and Asia, and in urbanized areas. This significant increase in population will require more water for human consumptive use, growing crops and foods, and economic activities such as industrial production and power generation.

4.2 URBAN DEVELOPMENT AND INFRASTRUCTURE NEEDS

Existing populations in developing countries are increasingly migrating to urban centers and most population growth is anticipated to occur in urban areas. This urbanization requires significant investments in water storage and distribution, as well as wastewater collection and treatment facilities. Underinvestment in water supply and treatment infrastructure often leads to a patchwork of incomplete, poorly maintained, and informal systems for obtaining drinking water and disposing of wastewater.

4.3 POLLUTION AND ENVIRONMENTAL DEGRADATION

Many pollutants threaten water supplies and are especially widespread in developing countries. This includes the discharge of raw sewage into source water supplies, industrial chemical wastes, contaminants from resource-extraction activities, and more. In addition to man-made pollution, environmental degradation by humans is taking its toll on source water quality. Deforestation, land use change, and land use practices are altering the landscape in ways that decrease water storage in soils and vegetation; decrease natural filtering of contaminants; increase sediment, nutrient, pathogen, and chemical pollutant loading; and decrease groundwater recharge.

4.4 GROUNDWATER DEPLETION

As populations increase and agricultural and industrial needs grow, there is more demand for water in developing countries. This is resulting in increased and often unsustainable pumping of groundwater. In many locations groundwater is being pumped faster than it is being replenished through natural recharge. In other places, so-called "fossil" groundwater, which is not naturally replenished, is being extracted. These groundwater resources may eventually be depleted. Human changes to the natural environment are also limiting natural recharge in some locations due to deforestation and land use changes that increase rainfall runoff, reducing rainfall penetration into soils. These human changes may also affect local and regional precipitation patterns.

4.5 INAPPROPRIATE GOVERNMENT POLICIES AND PRACTICES

National policies such as promoting development in water-limited regions, or providing water without charge or below cost can encourage or restrict the efficient use of water across different sectors. Government policies and practices such as stream channelization, deforestation to promote agriculture, and promoting development in flood plains can affect the vulnerability of communities to flooding. Policies and practices such as poor monitoring of septic fields, poor oversight of industrial operations, and release of untreated wastewater can adversely affect the quality of source water and negatively affect health and the environment.

4.6 POOR RESOURCE GOVERNANCE

In many circumstances, current practices in the governance of human or natural resources create vulnerability. For example, uncontrolled settlement of peri-urban areas in flood- or landslide-prone locations increases the vulnerability of communities to natural disasters. Likewise, poor governance of the resource itself can create vulnerabilities. For example, when there is no metering of water, collection of revenues based on usage, or an established system of water rights, water may be withdrawn from surface or sub-surface sources at unsustainable rates, and utility systems may be unable to operate or maintain infrastructure effectively. When there is not a governance regime for wastewater

Photo credit: Engility/International Resources Group.

treatment or disposal, sanitation problems and human health impacts may result. For a more detailed discussion of governance issues, see Section 6 of this annex and the *Governing for Resilience: An Annex to the USAID Climate-Resilient Development Framework* (USAID, Forthcoming).

4.7 POOR WATERSHED MANAGEMENT

Poor watershed management, which can involve deforestation, upstream channelization, diking, elimination of wetland ecosystems, and improper urban drainage infrastructure, can exacerbate the impacts of flooding. For example, poorly planned and managed urbanization has led to large-scale expansion of human settlements in floodplains. Furthermore, dikes and levees that may reduce upstream flood risk by channelizing and accelerating flood waters through a population center can increase downstream flood risk significantly through increased flow velocities and scouring of natural vegetation that attenuates flooding.

Photo credit: USAID.

4.8 INSUFFICIENT PLANNING, PERMITTING, AND ENFORCEMENT

Reliance on water-intensive livelihoods, lack of insurance, and inadequate community-support systems can exacerbate the impacts of droughts. Land use planning decisions can also exacerbate drought when population centers are located or agriculture is practiced on already drought-prone lands. Inadequate planning for seasonal or inter-annual storage capacity also heightens vulnerability to drought.

Non-climate stressors: The Iloilo case study example below provides a concrete example of identifying non-climate stressors and their relationship to the water sector – including poor distribution infrastructure (Section 4.2), pollution from sewage (Section 4.3), and fragmented water governance (Section 4.5). For the full Iloilo, Philippines case study, please see the USAID (2013) document *An Assessment of Water Security, Development, and Climate Change in Iloilo, Philippines and the Tigum-Aganan Watershed.*

Iloilo, Philippines — NON-CLIMATE STRESSORS

Metro Iloilo Water District (MIWD) water is treated at a modern water treatment facility constructed in 2000, and water leaving the treatment facility meets international standards for quality. However, the water that comes out of household and commercial taps is reported as muddy-colored and not safe for potable use, suggesting problems in the reticulation system and/or storage tanks. MIWD estimates that some 38% of water is lost from the system, further suggesting problems with the water distribution infrastructure. There is also no sewerage system in the metro Iloilo area. The Iloilo River receives untreated sewage from 120 of 180 barangays in Iloilo City and 50 additional barangays outside the city limits. There are currently no plans to provide a sewerage system, and existing septic systems were reported to be poorly maintained, leading to contamination of groundwater. Furthermore, water is subjected to a highly fragmented system of authority and control in the Philippines. National, regional, and local entities all play a role in water governance, but in many circumstances it appeared that local level control of the resource was hindered by conflicting authorities and mandates at the national level, lack of enforcement capability, local and national level politics, and opaque decision-making processes. The situation in Iloilo provides a clear example of how key non-climate stressors (i.e., poor distribution infrastructure, pollution from sewage, and fragmented water governance) can impact water resources.

5. CLIMATE IMPACTS ON WATER-RELATED SECTORS

The climate stressors described in Section 3 may impact the specific water resources sectors described in Section 2, such as water supply and sanitation, agriculture, or energy. We briefly examine these sector-specific climate impacts below.

5.1 WATER SUPPLY AND SANITATION

Water supply may be constrained by (1) long-term reductions in water availability in basins fed by shrinking glaciers, (2) longer and more frequent droughts or dry seasons, (3) decreased precipitation in the rainy season with less water available for storage during the dry season, (4) reductions in groundwater levels, (5) increased water demand due to enhanced evapotranspiration and the necessity to expand irrigation, (6) the salinization of surface water and groundwater, and (7) reduced rainwater capture due to increased runoff and less absorption by vegetation and soils. This reduced water availability may lead to groundwater over-exploitation, which can increase water costs and reduce water quality. Even in locations like South Asia, where precipitation is expected to increase, substantial investments in water storage and delivery infrastructures may be necessary to avoid seasonal or absolute water shortages.

Sea level rise in conjunction with over-extraction is leading to the salinization of coastal groundwater aquifers and small island freshwater lenses. This issue is particularly significant because approximately one-quarter of the world's population lives in rapidly growing coastal regions that are often water scarce. Saltwater intrusion may also affect inland aquifers due to a reduction in freshwater recharge caused by less rainfall or reduced soil permeability.

The populations that will likely be most affected by climate change are in the already water-stressed basins of Africa, the Mediterranean region, the Near East, South Asia, northern China, central and northern Mexico, northeastern Brazil, and the west coast of South America. According to Bates et al. (2008), "Those particularly at risk will be populations living in megacities, rural areas strongly dependent on groundwater, small islands, and in glacier- or snowmelt-fed basins (more than one-sixth of the world's population live in snowmelt basins)."

Photo credit: Engility/International Resources Group.

Water shortages can lead to uncontrolled water reuse, whereby polluted water or wastewater is used in a way that inhibits meeting sanitation objectives. Higher total precipitation or more intense precipitation events in cities may affect stormwater drainage and sewer systems, with consequent impacts on sanitation as well. Increased frequency and/or intensity of floods and droughts can affect sanitation as well.

5.2 AGRICULTURE, FOOD SECURITY, LAND USE, AND FORESTRY

Agriculture and related activities will be significantly affected by changes in water demand and availability. Increased evapotranspiration will increase vegetative water demand on the one hand. But on the other, changes in precipitation patterns will likely lead to more dry days and, in many cases, less available water during the growing season or over the course of the year. In general, modest warming combined with higher levels of carbon dioxide in the atmosphere (which generally increases plant growth and reduces plant demand for water) may be beneficial to agriculture in high latitudes, but low latitudes will likely see decreases in agricultural yields because these lands are often already near biological temperature or moisture thresholds.

The projected increased frequency of extreme events like floods, heat stress, and droughts will have further effects on agriculture and food systems through increased flooding, enhanced soil erosion, soil salinization, and crop stress due to heat waves and droughts. This will have significant impacts on rainfed agriculture. Most regions will also experience an increase in irrigation demand to account for the combination of increased evaporation and altered precipitation patterns. In general, food production is expected to decrease where precipitation decreases. Projections of increased aridity are robust across models for the Mediterranean, Southwest Asia, the Caribbean, Mexico, central and northern South America, and southern Africa.

More than 1 billion people in the developing world rely on fish as their principal source of animal protein. Freshwater fisheries and aquaculture are affected by the same climate impacts as described above for agriculture due to increased water temperature, increased oxygen demand, decreased pH, altered water quality

and flow regimes, disturbance from flooding and other extreme events, and the spread of invasive species, diseases, and pests. Marine fisheries are also affected by climate impacts on water resources because as much as 75% of commercially important marine fisheries are dependent, for at least part of their lifecycle, on estuaries (USAID, 2009). Marine fisheries are discussed in more detail in the *Climate Change and Coastal Zones: An Annex to the USAID Climate-Resilient Development Framework* (USAID, 2014a).

THE IMPORTANCE OF RICH FOOD FOR POOR PEOPLE

"FAO estimates that fish provides 22% of the protein intake in sub-Saharan Africa. This share, however, can exceed 50% in the poorest countries (especially where other sources of animal protein are scarce or expensive). In west African coastal countries, for instance, where fish has been a central element in local economies for many centuries, the proportion of dietary protein that comes from fish is extremely high: 47% in Senegal, 62% in Gambia, and 63% in Sierra Leone and Ghana. Equally important is the fish's contribution to calorie supply. Where there is a lack of alternative locally produced protein and/or where a preference for fish has been developed and maintained fish can provide up to 180 calories per capita per day" (World Fish Center, 2005).

Local people working at a fish farm in Mozambique.

Photo credit: USAID.

Freshwater fish, such as tilapia and other lake fish, play an important caloric and nutritional role in many developing countries. Climate change can have significant impacts on freshwater fisheries through changes in water temperature, flow regimes, and pollutant loading. These impacts can cascade into marine fisheries as discussed in the *Climate Change and Coastal Zones: An Annex to the USAID Climate-Resilient Development Framework* (USAID, 2014a).

Rangeland pasture is typically in semi-arid areas and already susceptible to water deficits. While modest warming can increase grassland productivity, especially at high latitudes, the productivity and composition of rangelands is more tightly correlated with moisture availability. Furthermore, changes in climate variability are likely to impact pasture and livestock. Consequently, the combinations of expected climate impacts and over-use of water resources will likely lead to significant declines in animal productivity and potential livestock loss in most areas, especially over the long-term.

Forests occupy about as much land as that used for crops and pastures combined. Forests are important for water supply, quantity, and quality in many countries, and will likely become more important over time as climate and other stressors increase the scarcity of freshwater resources. Forests also provide drought and flood mitigation benefits, especially in the tropics. Furthermore, forests have significant feedbacks on local climates, including greater humidity, lower temperatures, and increased rainfall. Once such areas are deforested for agricultural use or urban development, local climates change and the resulting climate conditions may not be conducive for afforestation. Forest ecosystems will be differentially impacted by climate variability and change depending on whether they are most sensitive to changes in temperature, precipitation, or disturbance regimes such as fire and pests.

5.3 HUMAN HEALTH

Climate impacts are expected to increase water scarcity and degrade water quality in many areas, which could have negative impacts on human health. Reduced surface water quantity and river flows can pose a human health risk because less water means less dilution of effluent and a higher probability of disease outbreaks. However, there is a lack of information connecting large-scale changes in climate to the population- or household-level impacts necessary to sufficiently analyze projected health outcomes from water quantity changes.

Drainage and stormwater management are important for the control of vector-borne diseases (e.g., malaria, yellow fever) and parasites, especially in low-income communities with poor sanitation. Higher temperatures, higher peak flows during the rainy season, and flooding events can all exacerbate diarrheal disease and other waterborne diseases, like cholera, which are tied to poor sanitation and lack of access to safe water. Flooding and heavy rainfall can also mobilize chemicals, heavy metals, sediments, and other hazardous substances and impair water quality. Harmful freshwater algal blooms that produce toxins leading to human disease may increase as river and lake temperatures warm.

5.4 SETTLEMENTS AND INFRASTRUCTURE

A wide variation in vulnerability exists within and across regions with regard to infrastructure. Nevertheless, small islands, arid or semi-arid developing countries, regions dependent on glacial- or snow-melt dominated water supplies, and countries with a high proportion of coastal lowlands tend to have particularly vulnerable settlements. Coastal megacities in the Asia-Pacific region deserve special attention as these settlements have more people who are highly vulnerable. In addition to water shortages, such settlements may also face risks from declines in water-related economic activities, reductions in fish as a food source, elimination of ecosystem services such as flood buffering from wetlands, and food shortages from increased competition between heightened irrigation needs for agriculture and greater demands for human consumptive use. Informal settlements, which are common in developing countries, are particularly vulnerable because they are often built on relatively hazardous sites, such as in floodplains or on steep hillsides susceptible to landslides.

URBAN FLOODING

According to a recent report from the World Bank, urban flooding has a greater impact on society than any other hazard. In response to this widespread threat, the World Bank proposed an integrated approach to urban flood risk management that includes both structural (e.g., drainage channels, dikes, levees) and non-structural (e.g., wetland restoration, land use planning) approaches that can complement one another (Jha et al., 2012). Climate change is expected to lead to more intense precipitation events, which may exacerbate urban flooding issues in many areas. (See Adaptation Actions 6 and 7 in Appendix A.)

Palmares of Pernambuco state damaged by flood.

Photo credit: Agência Brasil.

GLACIAL LAKE OUTBURST FLOODS

A glacial lake outburst flood (GLOF) is a sudden release of a large amount of water from a glacial lake that is many orders of magnitude higher than normal flow (Carrivick, 2006). GLOFs may be triggered by cascading ice from overhanging glaciers, landslides, or earthquakes, though they depend on the stability of the moraine dams. The rapid retreat of glaciers in the Hindu-Kush-Himalaya and Andes ranges, as anticipated by the warmer temperatures associated with climate change, has seen the formation of new or dramatically enlarged glacial lakes. For example, between 1972 and 2009, Lake Palcacocha in Peru increased in area (from 66,000 m^2 to 518,000 m^2) and in volume (from 579,000 m^3 to 17 million m^3). In 1941, a GLOF from this lake resulted in more than 5,000 deaths in the City of Huaraz (Somos-Valenzuela and McKinney, 2011).

Photo credit: Daniel A. Byers.

Infrastructures of concern associated with settlements include buildings, transportation networks, coastal facilities, energy facilities, water supply conduits, and stormwater and wastewater systems. Many of these facilities were not designed to cope with significant climate impacts and may be in physical or structural risk, may suffer impaired performance, or might face higher operating costs under changed climatic conditions. Flooding due to increases in intense precipitation events or glacial melt and associated erosion can have significant impacts on infrastructures, especially transportation networks located along rivers and coasts. In addition to flooding, landslides and severe storms (such as tropical cyclones) pose the greatest risks to buildings. Coastal facilities are typically low-lying and susceptible to flooding associated with higher-intensity tropical cyclones (in addition to storm surges and long-term sea level rise as discussed in the *Climate Change and Coastal Zones: An Annex to the USAID Climate-Resilient Development Framework* (USAID, 2014a). Freshwater storage facilities such as reservoirs and dams (small and large), dugouts, and other impoundments can be affected by changes in precipitation patterns, increases in evaporation, and extreme events like floods. Stormwater and wastewater infrastructures may also face significant capacity problems due to anticipated increases in intense precipitation events, even in locations projected to be drier on average. Changes in surface water flow will directly affect existing hydroelectric facilities as well as the design of future projects. Higher water temperatures can also affect the efficiency of thermoelectric power plants by reducing the cooling capacity of water.

5.5 ECOSYSTEMS AND BIODIVERSITY

LAKES

Increased summer water temperatures can increase the thermal stratification of lakes, which causes anoxia[6] in deep lakes and nutrient depletion in shallow lakes. Algal blooms can increase dramatically, altering the aquatic food web as well as water quality for human consumptive use. Furthermore, organic matter decomposition rates increase with temperature, further altering lake chemistry. Drying or salinization of lakes is also possible where precipitation and temperature changes combine to cause evaporative losses that exceed inflows. Finally, the range of invasive species, a major threat to native biodiversity and water quality, may increase with increasing temperatures.

STREAMS

In areas that already face large seasonal variation in flows, drying of streambeds is a significant possibility. This is also true of areas reliant on snow or glacier melt. In humid regions, where flows are less variable, ecological interactions tend to control the abundance of organisms. In these areas, temperature and precipitation changes may have a strong effect on stream ecosystems. Increases in stream temperature can restrict habitat for native biodiversity and extend the range of invasive species for streams as well. Increased flows, especially from extreme precipitation events, can scour streambeds and cause significant ecological damage to streams both in locations with projected increases and decreases in average precipitation.

FRESHWATER WETLANDS

Altered precipitation regimes and more frequent or intense droughts, storms, or floods can have significant effects on freshwater wetlands. Warmer temperatures can also lead to invasive species as well as wetland drying in conjunction with enhanced evaporation. Not only will such changes affect biodiversity (including likely significant extinctions, especially among amphibians and reptiles), but also reduce groundwater recharge, downstream water quality, and surface water availability. Due to their limited capacity for adapting to changing climate conditions, wetlands are considered among the most vulnerable ecosystems to climate change – including monsoonal wetlands such as the Sundarbans in India and Bangladesh, boreal peatlands, and African Great Lakes wetlands, among others.

COASTS AND ESTUARIES

Changes in the timing and volume of runoff can affect salinity and sediment and nutrient availability for coastal ecosystems. These ecosystems will be affected by changes in runoff, sea level rise, and coastal storm disruption in non-spatially uniform ways, which may lead to a significant range of potential impacts. Among these are alteration or complete loss of plant communities, increase of saline intrusion into coastal freshwater aquifers, increased coastal erosion (especially of river deltas), and significant alteration of estuaries in ways that may affect their habitability for a variety of biodiversity. Refer to the *Climate Change and Coastal Zones: An Annex to the USAID Climate-Resilient Development Framework* (USAID, 2014a) for a more detailed discussion of the implications of sea level rise on coasts and estuaries. See also USAID's guide, *Managing Freshwater Inflows to Estuaries: A Methods Guide* (USAID, Undated).

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6. Anoxic waters are areas of fresh- or saltwater that are completely depleted of oxygen. This can occur when density stratification due to salinity or temperature prevent the exchange between warmer, higher-oxygen, surface waters and cooler, lower-oxygen, deeper waters. Fish, and most other aquatic life, cannot live in anoxic conditions.

MOUNTAIN ECOSYSTEMS

Temperature and soil moisture are major factors defining mountain ecosystems, especially in watershed catchments dominated by snow or glacier melt. Changes in temperature and precipitation regimes can affect total water supply, water supply timing, alpine flora, pest infestations, and source water quality as well as the habitability of such ecosystems for particular species.

FORESTS, SAVANNAS, AND GRASSLANDS

The availability of moisture is a key factor in these ecosystems. Vegetative drought stress, which can affect plant growth and reproduction, and heat-induced fire susceptibility are two significant impacts that may be affected by climate change. Drought can lead to plant mortality due to disease, vegetative stress, and pest infestation. Warmer temperatures, reduced soil moisture, more dry days, and other potential climate changes can increase the likelihood and/or severity of wildfires as well. These changes can affect source water quality and surface water storage.

5.6 ENERGY

Photo credit: USAID/Afghanistan.

Increased population and development pressures will most likely increase the demand for both energy and water, even as climate impacts add new challenges to the energy/water nexus. Higher air temperatures will increase water temperatures, which will increase the evaporation of water from surface storage, slightly reduce the efficiency of electricity generation, and increase the volume of water needed for cooling thermoelectric power plants. In addition, decreases in rainfall are projected in many areas, and even areas with projected increases in annual average rainfall may experience more dry days and more rain falling in fewer high-intensity events. This can affect the viability of hydropower as well as the energy demands of raw water and wastewater treatment. Drought and flood events may increase in frequency and/or magnitude, affecting both energy and water infrastructure and the need for raw water treatment. Thus, the many climate impacts will likely increase pressure on both sectors as weather patterns change, potentially increasing the demand for, or restricting the supply of, each resource.

Without considering both energy and water together, one might look to water management options that increase energy needs significantly or energy sources that require substantial increases in water use. Considering only one of these two interconnected issues can lead to a reinforcing dynamic, whereby water resources are developed that require large energy inputs or energy sources are developed that require large water inputs.

Impacts: The Iloilo case study example below provides a concrete example of the difficulty of evaluating climate impacts in a data poor environment – a situation typical of many developing countries. For the full Iloilo, Philippines case study, please see the USAID (2013) document *An Assessment of Water Security, Development, and Climate Change in Iloilo, Philippines and the Tigum-Aganan Watershed.*

Iloilo, Philippines IMPACTS

Climate change impacts are likely to affect all aspects of water management in metro Iloilo. Projected increases in the variability of weather, changes in the timing and intensity of precipitation and storms, and sea level rise will impact water quality, water supply, and flood management capabilities. Current management decisions are often complicated by a lack of data. Future climate impacts will make this data-poor situation even worse as historical temperature and precipitation regimes shift over time. Developing a long-term monitoring program, including enhanced data collection, will provide information both about current conditions and how those conditions may change in response to climate change. These data can be used to improve water management decisions and ensure that those decisions are based on the best available information.

6. WATER AND GOVERNANCE ISSUES

Governance is a central issue for water resources. The sectors affected by water resources include water supply and sanitation; agriculture, food security, land use, and forestry; human health; settlements and infrastructure; ecosystems and biodiversity; and energy (as discussed in Section 2). Each and every one of these sectors is affected as climate stresses water resources, and good governance mechanisms and capabilities are critical to increase climate resilience in these sectors. Building adaptive capacity to manage climatic uncertainty and stress requires effective and participatory water governance to address conflicting needs from different economic sectors (Hill, 2013). How countries choose to govern their water resources has critical impacts on available opportunities for sustainable livelihoods and broader economic development. Water governance is defined by the political, social, economic, and administrative systems that are in place (both formally and informally), and which affect the ways in which water is used, developed, managed, and delivered at different levels of society.[7]

There are many competing uses of water, including for drinking, sanitation, agriculture, industry, transport, energy, recreation, and ecosystems. Ensuring sufficient access to the resource, especially in the face of climate impacts, requires inclusive and transparent processes to manage a potentially scarce resource. Information generation and management are often critical for the development of rational and effective policies. Estimates of water supply, demand, and flows over the year are needed to create rational systems for allocating water, managing water storage and withdrawals, and developing effective pricing structures. Many existing water allocation systems date to earlier periods of relative climate stability and must be modified to take account of a changing climate.

WATER RESOURCES MANAGEMENT IN CAMEROON

In Cameroon, water resources management is both a challenge and an imperative because the nation shares its rivers with neighboring countries. In addition, 99% of installed electricity generation capacity relies on hydropower. Conflicting priorities for water in many cities has led to power shortages and blackouts. IWRM is seen as a way to improve water management by encouraging public participation at the local council level, recognizing water as both an economic and social good, and putting water management within the larger context of integrated natural resource management (Ako Ako et al., 2010).

7. This definition is drawn from the definition of the United Nations Development Programme (UNDP) Water Governance Facility, available at www.watergovernance.org.

Water governance occurs at all levels, from the community-based systems for water management, through the municipal or basin level, all the way to the national and even transboundary levels. At the local level, water user associations, farmers' cooperatives, women's groups, and village committees can all play a role in the allocation, preservation, and distribution of water resources. At this level, enhancing basic water management skills and knowledge about the status of the resource can provide large dividends in the form of more efficient resource use. However, when conflicts arise at the local level or among local jurisdictions, higher-level authorities are sometimes needed. Moreover, given that hydrological and political boundaries rarely coincide, higher levels of governance or government can provide crucial oversight of local impacts and decisions. At the national level in many countries, the agriculture ministry has authority over water use for irrigation, the ministry responsible for public works has authority over flood control, and the environment ministry has authority over water quality, environmental flows, and basin-scale or watershed management. This often leads to policies and rules that do not manage water resources as an integrated system. While effective water governance is important in general to reduce conflicts at the local, state, regional, and national levels, it is particularly crucial to improving climate resilience. State, regional, or national level governments can issue water rights or permits, enforce legal rights, protect vulnerable communities and watersheds from exploitation, fund infrastructure to collect and store seasonal water during the rainy season as a source of water during the dry season, and more. The importance of incorporating climate adaptation in water governance needs to be emphasized at every level of government.

Human systems fundamentally determine resource use, wastewater production, and pollution of the resource; these systems must be taken into consideration when determining development priorities (GWP, 2000). An integrated approach that is multidisciplinary, strongly participatory, and cross-sectoral is well suited to tackling the complexity of human institutions interacting with water resources. For example, any water supply should be managed with consideration for agricultural policies and practices, such as irrigation schemes, subsidies for water-intensive crops, and consumption tariffs. Integrated management of water supplies may require local institutional arrangements, community awareness and participation, self-regulation, and implementation of demand-side measures to constrain total water demand (Foster and Ait-Kadi, 2012).

IWRM IN NAMIBIA

The application of IWRM in Namibia is an example of the effectiveness of basin level planning. Namibia's primary water source comes from the Kunene River, which the country shares with Angola. Namibia's Water Resources Management Act of 2004 established Basin Management Committees. These committees are responsible for developing water use plans, guaranteeing community participation, and establishing a cost-covering tariff system. There is also potential for the development of a bi national Cuvelai River Basin Commission between Namibia and Angola to improve coordination (Kluge et al., 2008).

It is also the case that the political and administrative bodies that manage water resources often struggle to cooperate on integrated management because of jurisdictional boundaries, institutional arrangements, and cultural aspects. As a result, many of the changes in structures and procedures necessary for effectively managing water resources may require significant modifications in governance systems. These changes in governance typically involve (1) expanding geographic jurisdictional boundaries (e.g., enabling management on an entire watershed so that downstream impacts from upstream activities are taken into account); (2) broadening natural resource management jurisdictional boundaries (e.g., so that the impacts of land use activities and regulations on water resources are fully taken into account); and (3) expanding sectoral governance jurisdictional boundaries (e.g., so that the competing needs and impacts of the many water-

dependent sectors – such as energy, agriculture, industry, and municipal – are properly weighed and balanced). Strengthening water governance to more effectively manage water resources may also require establishing and supporting water-related institutions and governance systems that take explicit account of climate change. Cook et al. (2011) identify principles of climate-adaptive institutions such as managing resources in a flexible manner to account for climate impacts, incorporating adaptation into all operations, engaging in partnerships, having a visionary champion to implement a strategy that addresses climate change, and operating internally and externally in an equitable and transparent manner. Changes in governance often entail significant challenges, including the need for effective multi-national and sub-national cooperation since river basins and fossil aquifers often cross multiple borders. For a more detailed discussion of governance issues, we recommend referring to the *Governing for Resilience: An Annex to the USAID Climate-Resilient Development Framework* (USAID, Forthcoming).

7. PRINCIPLES OF ADAPTATION FOR THE WATER SECTOR

In order to address climate vulnerability, it is useful to start with what has been learned by others. A large body of work has already been done on adapting to climate impacts, and in this section we discuss some of the best practices and lessons learned.

The key to taking action to address climate vulnerability is first to understand how climate impacts might affect specific objectives for any particular water resources issue. For example, basic development objectives may be the driving force behind a new water supply project, including providing potable water to an expanded population, increasing the reliability of water for agricultural uses, or reducing disease incidence. The purpose of considering adaptation actions is to ensure that climate impacts will not significantly impede efforts that are essentially intended to help countries develop. We call this the "development-first approach" (see USAID, 2014b).

It is important to recognize that many adaptation actions often do not require a vastly different manner of thinking, doing business, or the development of significant changes in policy or operations. The changes are often incremental and have multiple benefits. While some adaptation actions may address only climate change, more often such actions address non-climate stressors and natural climate variability as well. In other words, most adaptation actions create a more resilient water system in the face of severe drought and population growth, as well as climate change. Nevertheless, some aspects of climate change can pose serious risks to many water systems and may require more significant changes, especially where long-lived and high-cost infrastructure investments are under consideration.

Below are some strategic-level best practices for managing climate vulnerability. This advice is provided in the form of "principles of adaptation." These are meant to provide different ways of approaching climate change adaptation that have been successful in the water sector, in other sectors, in other regions, and at various levels of government. For more extensive evaluations of climate change adaptation in the water sector, we recommend Brown (2010), Wilby and Dessai (2010), Stakhiv (2011), and Brown and Wilby (2012).

7.1 "MAINSTREAM" ADAPTATION

Rather than create an entirely new or parallel set of programs and policies to cope with climate vulnerability, it is generally better to incorporate consideration of climate impacts into existing decision-making, a concept known as "mainstreaming." The best starting point for addressing climate impacts is where established personnel or processes already are making water-related decisions because that leverages existing resources, requires minimal resources to implement, avoids the disruption that reorganization can create, and generates less opposition than creating new institutions. This, in fact, is the very premise underlying the new USAID (2014b) climate-resilient development framework and its development-first approach.

7.2 ENGAGE IN "NO-REGRETS" DECISION-MAKING

No-regrets decisions make sense under current and historical climate conditions and pay dividends regardless of what happens in the future. For example, increasing storage capacity or reducing system losses during the rainy season often leads to more water being available for a number of purposes during the dry season. Investing in such projects provides immediate benefits by reducing vulnerability to seasonal shortages, but may also provide additional benefits under climate change if droughts worsen or seasonal dry periods become longer or drier. While some may object that the idea of no-regrets is not sufficiently ambitious to tackle the challenges of climate change, developing countries often face significant infrastructure and capacity deficits that often make no-regrets decisions a necessary first step to a more climate-resilient future. A strategy that is comprised only of no-regrets options may not be sustainable over the long term as climate change results in substantial impacts, but can help to address changes that are evident and assist with the long-term transition.

7.3 PREPARE FOR MULTIPLE POSSIBLE CLIMATE FUTURES

Although this annex describes the state-of-the-science regarding climate impacts on water resources, there is still much uncertainty involved in making such projections. Thus, rather than looking for a single answer for what the future holds from the scientific community, managers and planners should prepare for the possibility that there could be a range of future climate conditions with greater variability. A future with less overall precipitation and more fires might require a different approach than a future with more overall precipitation and more flooding. Ideally, one should seek out strategies that provide vulnerability reductions under multiple plausible future climate conditions. It can also be productive, and sometimes more politically palatable, to consider climate variability that extends beyond the observed record in order to incorporate instances of more severe drought or floods than have been captured in the instrumental record.

7.4 ACKNOWLEDGE THAT CLIMATE VARIABILITY AND CHANGE ARE FUNDAMENTAL DRIVERS OF WATER RESOURCES SYSTEMS

To ensure that climate impacts are taken into account, all water managers, policymakers, and other personnel involved in water resources should explicitly consider the impacts of climate change as well as climate variability in all management, planning, and policy actions. Such consideration is often in the form of vulnerability assessments. These assessments consider if and how current weather and climate or projected future changes would affect the objectives of a project, an agency, or the resource it manages. Such vulnerability assessments, however, should inform the identification and selection of adaptation actions as discussed in Section 8.

7.5 PROMOTE ADAPTIVE MANAGEMENT

Rather than making a decision or crafting a plan and following it rigidly, adaptive management entails reviewing policies, plans, management practices, and operations during implementation to ensure that the desired objectives are being met. It can also mean postponing some decisions or making partial decisions (e.g., purchase the land needed for storage, but do not build the dam and reservoir now) until better information becomes available. This is particularly salient for climate change, where new information and evolving climate conditions may warrant changes to current strategies. Adaptive management is also important to ensure that unintended consequences of adaptation actions can be avoided or addressed in a timely manner. This is particularly important for water resources, which are often shared among sectors and limited in availability.

7.6 LEARN FROM BEST PRACTICES

Many decision-makers are managing the effects of existing climate variability, while others have begun to actively prepare for climate change. For example, emergency managers are prepared to deal with a wide variety of natural hazards as well as the occasional extreme event. The same principles used in the emergency management context could be used in dealing with long-term climate variability and change. In addition, decision-makers can review actions taken by other levels of government, other sectors, or other regions to look for lessons learned and policy innovations that can be applied in their own circumstances.

7.7 REMOVE BARRIERS TO ADAPTATION

Some existing laws, funding mechanisms, and management approaches were put in place assuming that the climate does not change over the long-term. As a result, some of these approaches can function as barriers that discourage or prohibit adaptation to a changing climate or promote behavior that increases climate vulnerability. For example, subsidies can encourage overconsumption, and they can even mask shortages brought on by climate variability or change. In addition, in many developing countries, weak legal frameworks, unenforced regulations, poor institutional and human capacity, and inadequate resource tenure and rights systems limit the available options for improving water resources management. It is critical for government agencies to recognize and remove the barriers of outdated management approaches that constrain the variety of options available to best manage climate impacts.

7.8 RECOGNIZE THE SCALES AT WHICH DECISIONS ARE MADE

Adaptation decisions will have to be made at multiple geographic and decision-making scales from individual farmers to national ministries to international development agencies. It is important to recognize the capacities as well as the limitations of any particular climate vulnerability so that suitable adaptation actions are proposed at the appropriate level. Temporal scales are also relevant. Some climate impacts will have near-term effects while others will consist of slow-onset challenges. An awareness of the temporal scale of anticipated climate impacts, as well as proposed adaptation options, will be important to select sensible adaptation actions that address near- and long-term impacts under limited resource conditions.

7.9 TAKE ADVANTAGE OF CLIMATE OPPORTUNITIES

Instead of looking only at the negative impacts of climate variability and change, it is useful to consider whether one can take advantage of some climate impacts. For water resources that could mean taking advantage of increased total annual precipitation – even if there are longer seasonal dry periods – by developing more storage capacity. Or it could mean thinking more broadly across the landscape and fostering cooperative efforts across regions, watersheds, or national boundaries. For example, as increasing temperatures lead to greater evaporation in the lowlands of India, it might make sense to work with Nepal to develop high-mountain water storage options.

8. OVERVIEW OF ADAPTATION ACTIONS

We include an appendix to this annex that discusses a number of categorical actions that can be taken to reduce climate vulnerability. We outline the basic categories of adaptation actions below and provide a basic introduction for each action. This section is intended to stimulate thinking about potential adaptation actions that can decrease vulnerability to climate and non-climate stressors. For a more detailed discussion of each action, see the adaptation action descriptions in Appendix A.

Within USAID's adaptation pillar of programming, three categories of priority activities are identified:

- ***Improved governance to address climate-related risks***. Adaptation activities can promote improved public communication and education, participatory policymaking and planning, and strengthened advocacy at the community, civil society, and private sector levels to influence climate decision-making. Agencies can support processes that include a broad range of partner country stakeholders in consultation and in decision-making activities, including women and traditionally marginalized populations. This will include working with government ministries and agencies concerned with climate to ensure that they engage in adequate and broad-ranging consultation and coordinate vertically (i.e., across scales) and horizontally (i.e., across institutions) at both the planning and implementation stages.
- ***Improved science and analysis to inform decision-making in topics sensitive to climate***. Adaptation activities may invest in improving partner country scientific capacity and access to and use of climate information and evidence-based analysis. This is important to help societies identify vulnerabilities and evaluate the costs and benefits of potential adaptation strategies. The more appropriate, comprehensive, and accessible the data and analysis, the better the choices decision-makers from the community to the national level can make to reduce climate vulnerability.
- ***Piloting, implementing, and evaluating effective adaptation strategies to address climate-related risks***. Adaptation activities can support site-specific, on the ground actions to reduce climate vulnerability in sectors including agriculture, health, urban planning and infrastructure, water management, and disaster risk reduction. These activities should target specific climate stresses of concern, and should focus on demonstration and learning about what works, does not work, and why.

The first nine adaptation actions described below largely fall into the third category of piloting, implementing, and evaluating adaptation strategies, although both information[8] and governance[9] issues are important in several of these adaptation actions. The tenth adaptation action focuses specifically on governance issues. The adaptation actions are grouped here into categories of increasing water availability (Actions 1–4), ensuring water quality (Action 5), limiting flood and inundation damage (Actions 6–7), preserving and enhancing ecosystems and ecosystem services (Action 8), integrated regional and multi-sector (e.g., coordinated energy and water sector) planning (Action 9), and strengthening water governance (Action 10). However, many of the particular adaptation actions discussed also have important co-benefits that apply to other categories. See Exhibit 4 below for illustrative examples of adaptation actions, numbered in accordance to how the adaptation actions are categorized in the appendices.

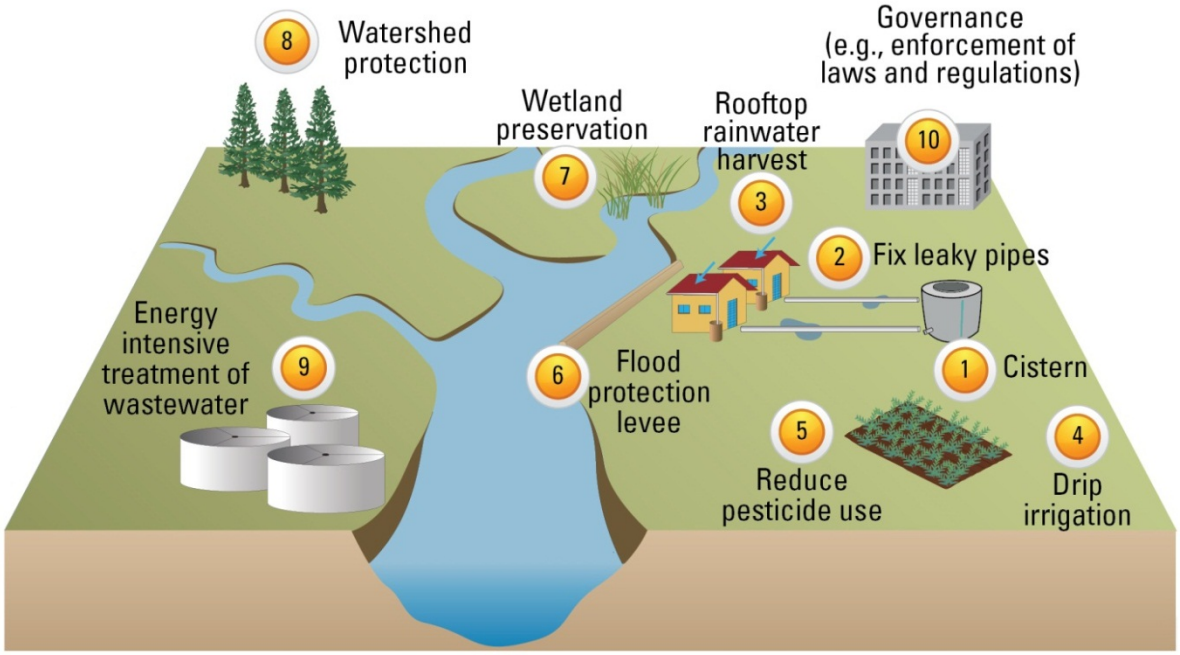

EXHIBIT 4. ILLUSTRATIVE EXAMPLE OF WATER SECTOR ADAPTATION ACTIONS. The numbers in the exhibit correspond to the adaptation action number in the appendix and in Sections 8.1 through 8.6 below.

8. Scientific information on climate variability and change is needed to support decision-making on climate-sensitive resources. In many cases, especially in developing countries, practitioners may be working with limited scientific information (e.g., a poor climate observation network or a record with many data gaps). Improved science and analysis may be a necessary precursor to prioritize among competing adaptation actions. In such cases, it is appropriate to enhance the generation of scientific information to support decision-making. We emphasize, however, that many adaptation actions can reduce climate vulnerability in the near-term, even with preliminary or incomplete information or data; this generally is the case for no-regrets adaptation actions.

9. Governance can be a critical foundational issue that defines the sustainability, effectiveness, and practicality of any given adaptation action. The recognition of the importance of governance is evidenced by Section 6 in this annex, which focuses explicitly on water and governance issues, as well as USAID's development of a separate annex on governance issues (USAID, Forthcoming). Particularly in developing countries, directly addressing governance issues may be critical to enabling many adaptation actions and may be worth pursuing in their own right. However, because many governance challenges can be difficult and time-consuming to tackle, it is important to concurrently look for opportunities to take action that improves water system resilience despite a non-optimal governance context.

8.1 INCREASE WATER AVAILABILITY

Adaptation actions, especially those in a water-stressed system, effectively focus on water supply or water demand in order to identify adaptation actions that can increase the availability of water. These two basic strategies of supply enhancement and demand reduction play out in the adaptation actions below in different ways because the context of a specific water resources system often dictates which adaptation actions will be both feasible and effective.

DETAILED DISCUSSIONS OF ADAPTATION ACTIONS

See Appendix A for detailed discussions of each adaptation action identified in this section.

ADAPTATION ACTION 1 – INCREASE OR STRENGTHEN WATER CAPTURE AND STORAGE

Water storage is the ability to capture and store water during times of excess precipitation or stream flow, for use during times of greater need. Water storage can be a very important climate adaptation strategy as the variability and predictability of current precipitation patterns change within and across years. Storage can decrease the vulnerability of a community to short- and long-term dry periods by providing supplemental water resources that can be available when natural precipitation or stream flow is inadequate to meet demands. By making water available at times it would not be available naturally, water storage can significantly increase human welfare, agricultural yields, and economic productivity. This adaptation action focuses on options for storing water above-ground in cisterns, dams, impoundments, and reservoirs and below-ground in the soil and aquifers. The impact of storage on water quality will be discussed in *Adaptation Action 5: Protect Water Quality* and the impact on ecosystem health will be discussed in A*daptation Action 8: Protect Inland Freshwater Ecosystems and Ecosystem Services*.

ADAPTATION ACTION 2 – REDUCE WATER LOSSES

As the demand for and value of existing water resources increases, controlling water losses and maximizing the efficiency of water use will become more important. Preventing or controlling seepage, evaporation, unauthorized water withdrawals, and waste are all methods to combat water losses from canals, reservoirs, and water distribution systems. Controlling water losses is one strategy that is often used in conjunction with developing more water storage (*Adaptation Action 1: Increase or Strengthen Water Capture and Storage*), finding new water sources (*Adaptation Action 3: Create New Sources of Water*), or making the most of existing resources through reducing demand (*Adaptation Action 4: Water Demand Management*). In many cases the strongest adaptation action will include a combination of all these actions. Note that the measures discussed often can be justified without considering climate change. The potential reductions of water supplies and the increased demand for water resulting from climate change make these measures more imperative.

ADAPTATION ACTION 3 – CREATE NEW SOURCES OF WATER

New and additional sources of water will be needed as climate impacts the availability and reliability of existing water sources. Options such as rainwater harvesting, grey water recycling, wastewater reuse, and desalination can increase water supply by taking advantage of water that was previously considered unusable. Short- and long-term droughts, increased demand, changes in water quality, and higher water losses will increase pressures on many existing water resources. Extreme events such as tropical storms or floods may make traditional water sources temporarily unavailable. New and additional sources of water will be needed to provide the flexibility to adapt to climate impacts.

ADAPTATION ACTION 4 – WATER DEMAND MANAGEMENT

Water demand management (WDM) is the adaptation and implementation of a strategy or program by a water institution or consumer to influence water demand and usage. WDM is most often associated with efforts to conserve water (i.e., use less water, or using water more efficiently), and often results in significant reductions in energy use as well (e.g., for pumping and treating water). WDM is typically implemented in order to meet one or more of the following objectives: economic efficiency, social development, social equity, environmental protection, and sustainability of water supply and services. WDM can be a valuable tool for increasing resilience to climate impacts on water availability, accessibility, and quality. The WDM process is strategic in promoting and increasing water use efficiency and the use of water-saving methods and technologies in order to help reduce pressure on water resources due to population growth, intensive land use, trans-boundary water management issues, and climate variability and change.[10]

8.2 ENSURE WATER QUALITY

Water quality is often overlooked because water supply is a more immediate need. However, there is an important interplay between water supply and water quality, because high-quality water is needed for many things, especially human consumption. Consequently, *Adaptation Action 5: Protect Water Quality* should be thought of in the broader context of all water resources.

ADAPTATION ACTION 5 – PROTECT WATER QUALITY

Access to high-quality water is essential for protecting human health, economic activities, and ecological functions. Currently, obtaining high-quality water is a significant challenge in developing countries and numerous efforts are ongoing to improve delivery of safe, high-quality water. Because climate impacts are likely to exacerbate water quality challenges, this adaptation action focuses on options to improve access to high-quality water and improve the resilience of high-quality water supplies to climate impacts.

This water quality adaptation action overlaps significantly with two other adaptation actions. Water quality as it relates to ecosystem services is covered in *Adaptation Action 8: Protect Inland Freshwater Ecosystems and Ecosystem Services*. Wastewater reuse, an important action to protect water quality, is discussed in *Adaptation Action 3: Create New Sources of Water*.

8.3 LIMIT FLOOD AND INUNDATION DAMAGE

Flood and inundation damage is the greatest source of economic damages from all disasters. Especially in developing countries, there are a large number of opportunities for reducing the vulnerability of people and property to flood damage. The adaptation actions below discuss two major categories of action – structural and non-structural.

ADAPTATION ACTION 6 – STRUCTURAL APPROACHES TO FLOOD PROTECTION

Structural adaptation approaches can help protect vulnerable lands, people, infrastructure, and resources from destructive inundation caused by increased flooding and sea level rise. These approaches can include (1) structures and armoring that protect existing settlements by shielding them from inundation, (2) accommodating climate change by designing structures to withstand anticipated impacts, and (3) retreating to avoid destructive inundation. Major implementation issues to consider include selecting an appropriate

10. Water reuse and recycling can be categorized as a WDM option. It can also be described as the creation of a new water source. In this guide, the option will be categorized a substitute source of water that meets suitable types of demands and end uses, and is covered in *Adaptation Action 3: Create New Sources of Water.*

design, costs, external demographic drivers, potential unintended negative consequences, and development goals. It can be beneficial to implement structural options alongside non-structural adaptation measures (see *Adaptation Action 7: Non-structural Approaches to Flood Protection*). Note that *coastal* flooding is discussed in more detail as part of the coastal annex to the USAID climate-resilient development framework (USAID, 2014a).

ADAPTATION ACTION 7 – NON-STRUCTURAL APPROACHES TO FLOOD PROTECTION

Non-structural approaches to flood and inundation protection include strategies to promote the ability of natural systems to moderate flood waters and help people prepare, avoid, and recover from flood events. This adaptation action focuses on non-structural approaches that fall into three broad categories: (1) preservation, creation, or enhancement of natural buffering systems; (2) land-use planning and policies; and (3) disaster preparation, response, and recovery. Non-structural options can also be implemented alongside structural adaptation measures (see *Adaptation Action 6: Structural Approaches to Flood Protection*). Non-structural options can offer flexibility over time as well as environmental and developmental co-benefits, making them an important component of a comprehensive adaptation strategy. Note that *coastal* flooding is discussed in more detail as part of the coastal annex to the USAID climate-resilient development framework (USAID, 2014a).

8.4 PRESERVE AND ENHANCE ECOSYSTEMS AND ECOSYSTEM SERVICES

Ecosystems often provide critical services that have economic value to many developing countries, such as pollutant filtration, groundwater recharge, and flood control. Ecosystems also support important industries in many developing countries, such as tourism and fisheries.

ADAPTATION ACTION 8 – PROTECT INLAND FRESHWATER ECOSYSTEMS AND ECOSYSTEM SERVICES

Inland freshwater ecosystems, including rivers, lakes, and wetlands, provide many important ecosystem services. Water supply-related ecosystem services include flow regulation and groundwater storage. Water quality-related ecosystem services include control of erosion and processing of wastes, pollutants, and contaminants. Agriculture, fisheries, tourism, and other sources of livelihoods are also dependent on freshwater. This adaptation action focuses on protecting inland freshwater ecosystems and the services they provide through adaptation strategies that promote best management practices to protect/restore key ecological resources, enhance governance mechanisms, and build institutional capacity.

8.5 INTEGRATED REGIONAL AND MULTI-SECTOR PLANNING

Because climate impacts can increase the stress on many individual sectors, they heighten the cross-sectoral stresses involving water. This increases both the need for and value of applying an integrated, cross-sectoral lens to water resources issues to look for holistic solutions for these issues.

ADAPTATION ACTION 9 – MANAGE CRITICAL INTERDEPENDENCIES BETWEEN ENERGY AND WATER

Energy and water are closely linked. The extraction, distribution, and treatment of water require the use of energy, and the production of energy requires the use of water (Haas, 2009). As the world population increases and economies develop, demand for both energy and water will grow in the coming decades. Projected changes in climate will likely put stress on both water and energy supplies. This adaptation action focuses on the critical interdependencies between energy and water and describes potential measures that can be taken to increase the resiliency of these essential resources to the impacts of climate change.

8.6 WATER AND GOVERNANCE

How water managers choose to govern their water resources has critical influence on the sustainability, effectiveness, and practicality of any given adaptation action as well as other development interventions. Adaptation actions that strengthen water governance complement and enhance other adaptation actions, such as those described above. In addition, the social, political, and economic context (i.e., the political economy) surrounding some of these other adaptation actions often require a degree of governance intervention in order for the actions to have a realistic chance of success.

ADAPTATION ACTION 10 – STRENGTHEN WATER GOVERNANCE

In general, strong governance is important for all adaptation actions – including those in the water sector because (1) weak governance frameworks are an obstacle to the creation and implementation of sustainable adaptation actions, (2) the political economy of the communities and countries in which adaptation is taking place shapes the feasibility and comparative effectiveness of various potential climate-related interventions, and (3) adaptation actions present a window of opportunity to integrate governance-strengthening initiatives into sectoral reforms, which creates a stronger enabling environment for sustainable development and a more robust framework for implementing the programs of which they are a part. This adaptation action focuses on options for building capacity for better water governance, and identifies specific options that can be effective in all locations, regardless of local political, economic, and social conditions. These options include such things as (1) decentralizing water decision-making; (2) adopting catchment management approaches; (3) clarifying institutional roles and responsibilities and developing coordination mechanisms; and (4) increasing compliance assistance and enforcement capacity.

8.7 COMBINING ADAPTATION ACTIONS IN CASE-SPECIFIC CONTEXT

Although the individual sections above described individual categories of adaptation actions, it is important to note that there are likely to be many instances in which the most prudent and effective path for climate-resilient development will entail the integrated application of a suite of water-related adaptation actions, drawn from multiple categories of adaptation actions. For example, in the face of increasing climate stress, there will be many locations where planners need to consider how to ensure the adequacy of future water supplies to meet growing future demands. In such a situation, it is likely that an integrated mix of adaptation actions will make the most sense, including options drawn from *Adaptation Action 1: Increase or Strengthen Water Capture and Storage*, *Adaptation Action 3: Create New Sources of Water*, and *Adaptation Action 4: Water Demand Management*, among other categories. The chart below provides one example of evaluating a broad suite of adaptation actions to enhance water security in Iloilo, Philippines.

Adaptation actions: The Iloilo case study example below provides a concrete example of the context-specific identification of adaptation options, as well as a preliminary evaluation of those adaptation actions. For the full Iloilo, Philippines case study, please see the USAID (2013) document *An Assessment of Water Security, Development, and Climate Change in Iloilo, Philippines and the Tigum-Aganan Watershed.*

Iloilo, Philippines — ADAPTATION ACTIONS

Summary table for all 22 adaptation actions in Section 6 of the Philippines document

Option	Category				Vulnerability addressed			Effectiveness	Feasibility	Cost	Implementation timing		
	Infrastructure	Capacity building	Policy/ governance	Good mgmt practices	Water quality	Water supply	Flooding				Short	Medium	Long
1.A Develop long-term water security and climate change monitoring program		✔		✔	✔	✔	✔	Medium	Medium	Medium	✔	✔	✔
1.B Evaluate and enhance groundwater for the Metro Iloilo area		✔				✔		Medium	High	Low	✔	✔	
2.A Enhance monitoring network for supply, quality, and flooding	✔	✔		✔	✔	✔	✔	Medium	Medium	High		✔	✔
2.B Develop an information clearinghouse for all water-related data in Metro Iloilo and the TAW		✔			✔	✔	✔	Medium	Low	Medium	✔	✔	
2.C Develop capacity for information-based management decisions among municipal and provincial resource managers		✔		✔		✔		Low	High	Low	✔		
3.A.1 Implement rainwater harvesting in the Metro Iloilo area	✔	✔				✔		High	High	Low	✔	✔	
3.A.2 Develop community-based potable water supplies	✔	✔				✔		High	High	Low	✔	✔	
3.A.3 Pursue demand side management in the Metro Iloilo area			✔	✔		✔		High	Medium	Low	✔		
3.B.1 Reduce MIWD non-revenue water	✔			✔		✔		High	Medium	High	✔	✔	
3.B.2 Conduct a feasibility study of MIWD treatment of Jalaur water	✔				✔	✔		High	High	Medium	✔		
4.Evaluate point of use source water treatment for near-term potable water provision	✔	✔			✔			Medium	Medium	Medium	✔		
4.B Improve compliance and enforcement capacity to achieve water quality goals		✔	✔		✔			Medium	High	Low	✔		

9. SUGGESTED RESOURCES

This section presents a list of recommended resources for further reading on the topics discussed in this annex. Many of these resources are cited throughout the annex, but additional resources are also included that may be of interest to development practitioners.

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APPENDIX A: ADAPTATION ACTIONS

Climate stressors contribute to the three main categories of water-related challenges: too little water, too much water, and/or degraded (i.e., low-quality) water. For example, droughts and floods are already risks virtually everywhere. Decreases in rainfall are projected in many areas, and even areas with projected increases in annual average rainfall may experience greater rainfall variability (e.g., more dry days and more rain falling in fewer high-intensity events). Drought and flood events that have already been experienced (and may not be sufficiently adapted to) may increase in frequency and/or magnitude. In addition, higher temperatures will most likely increase evaporation of water from surface storage, and also increase the demand for water for irrigation and other purposes. Increased population and development pressures will further increase the competition for water even as the predictability of water supplies declines.

This appendix describes a number of adaptation actions that can be employed to improve water sector resilience to potential climate impacts. Each section of the appendix describes a category of adaptation actions in detail (e.g., *Adaptation Action 1: Increase or Strengthen Water Capture and Storage* discusses various options for enhancing water capture and storage). Once a development practitioner has decided on a type of adaptation action to employ, these sections can be read as standalone documents that (1) discuss how that category of options contributes to climate resilience, (2) describe a variety of specific options within that category, and (3) explore some important implementation considerations.

INTEGRATED WATER RESOURCES MANAGEMENT – AN OVERARCHING PRINCIPLE FOR CLIMATE-RESILIENT DEVELOPMENT

Although the rest of this appendix describes individual categories of adaptation actions, it is important to note that there are likely to be many instances in which the most prudent and effective path for climate-resistant development will entail the integrated application of a suite of water-related adaptation actions, drawn from multiple categories of adaptation actions. For example, in the face of increasing climate stress, there will be many locations where planners need to consider how to ensure the adequacy of future water supplies to meet growing future demands. In such a situation, it is likely that an integrated mix of adaptation actions will make the most sense, including options drawn from *Adaptation Action 1: Increase or Strengthen Water Capture and Storage*, *Adaptation Action 3: Create New Sources of Water*, and *Adaptation Action 4: Water Demand Management*, among other categories. There are also often a wide variety of specific options within each category that can be strategically linked to increase their effectiveness.

IWRM is a holistic management approach that offers a promising strategy for both addressing existing water quantity and quality challenges and for improving the resilience of natural and human communities to the projected impacts of climate change on water resources. IWRM promotes coordinated development and management of water, land, and related resources in order to maximize economic, social, and environmental welfare. The integrated nature of IWRM means that elements of this approach will involve many of the other adaptation actions discussed at greater length in the remainder of the appendix.

IWRM is based on four principles articulated at the International Conference on Water and the Environment in Dublin, Ireland, in 1992. The Dublin principles are:

1. Fresh water is a finite and vulnerable resource, essential to sustain life, development, and the environment
2. Water development and management should be based on a participatory approach involving users, planners, and policymakers at all levels
3. Women play a central part in the provision, management, and safeguarding of water
4. Water has an economic value in all its competing uses and should be recognized as an economic good

These principles define the orientation of IWRM and inform the techniques that can be applied to achieving the goal of sustainable water management. The challenge lies in implementing water management structures and policies that embody these principles.

IWRM seeks to balance the interests of upstream and downstream water users through coordinated basin planning that looks for a more equitable solution to water needs across the basin rather than optimizing water resources use for just one community. This can be a particularly difficult problem when these communities or users reside in different political or administrative jurisdictions. IWRM's emphasis on basin level planning seeks to integrate the interests of both upstream and downstream users into the development of sustainable water management plans.

This means, however, that human systems (e.g., systems of governance) must be integrated into IWRM to improve success. IWRM does this by accounting for three basic components of the human system. First, an IWRM approach seeks to ensure that governmental policies, financial priorities, and planning take into account the implications for water resources development, water related risks, and water use. Second, IWRM encourages policies that influence private sector decision-makers to make technological, production, and consumption choices based on the real value of water and on the need to sustain natural resource assets over time. Finally, the IWRM approach emphasizes the importance of providing mechanisms to ensure that all stakeholders can participate in water resource allocation decisions, conflict resolution, and trade-off choices.[11]

SPECIFIC ADAPTATION ACTIONS

The remainder of this appendix describes individual adaptation actions, many of which can be a part of an IWRM strategy. These actions are as follows:

- Adaptation Action 1: Increase or Strengthen Water Capture and Storage
- Adaptation Action 2: Reduce Water Losses
- Adaptation Action 3: Create New Sources of Water
- Adaptation Action 4: Water Demand Management
- Adaptation Action 5: Protect Water Quality
- Adaptation Action 6: Structural Approaches to Flood Protection
- Adaptation Action 7: Non-structural Approaches to Flood Protection
- Adaptation Action 8: Protect Inland Freshwater Ecosystems and Ecosystem Services
- Adaptation Action 9: Manage Critical Interdependencies between Energy and Water
- Adaptation Action 10: Strengthen Water Governance

11. For more on IWRM, see this report by the Global Water Partnership: GWP (2000) Integrated Water Resources Management. Global Water Partnership Technical Advisory Committee Background Paper No. 4. Available: http://www.gwptoolbox.org/images/stories/gwplibrary/background/tac_4_english.pdf.

Exhibit A.1 illustrates many of the adaptation actions described in this appendix with numbers corresponding to the bulleted list. Although not all of the specific options within each adaptation action category are included in this schematic, this illustration provides a visual representation of the types of adaptation actions that communities might adopt. Note that some adaptation actions serve more than one category. Note also that some categories can be addressed using a variety of actions illustrated in the exhibit.

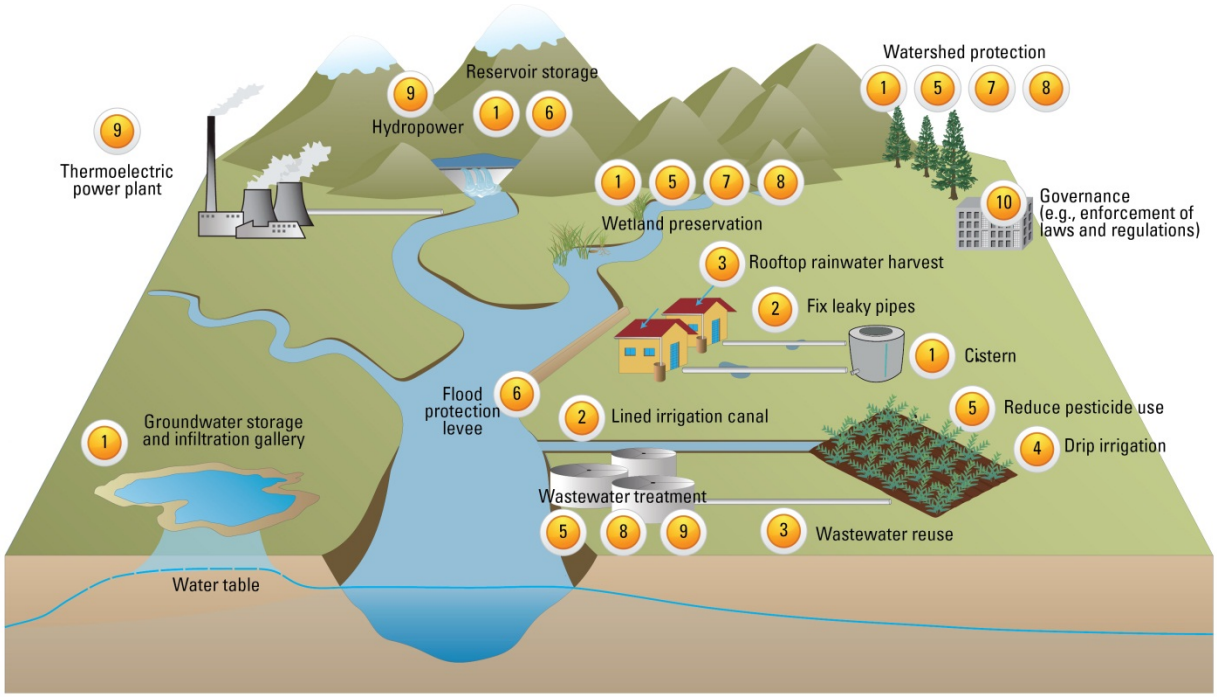


EXHIBIT A.1. ILLUSTRATIVE EXAMPLES OF WATER SECTOR ADAPTATION ACTION. The numbers in the exhibit correspond to the adaptation action number in the appendix and below.

- Adaptation Action 1: Increase or Strengthen Water Capture and Storage
- Adaptation Action 2: Reduce Water Losses
- Adaptation Action 3: Create New Sources of Water
- Adaptation Action 4: Water Demand Management
- Adaptation Action 5: Protect Water Quality
- Adaptation Action 6: Structural Approaches to Flood Protection
- Adaptation Action 7: Non-structural Approaches to Flood Protection
- Adaptation Action 8: Protect Inland Freshwater Ecosystems and Ecosystem Services
- Adaptation Action 9: Manage Critical Interdependencies between Energy and Water
- Adaptation Action 10: Strengthen Water Governance

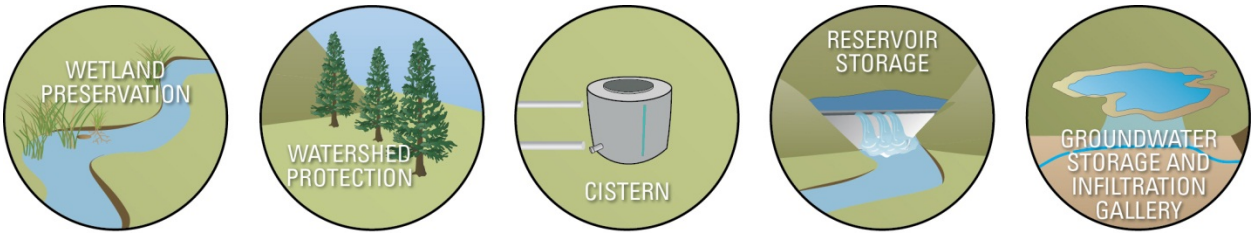
Development practitioners should recognize that some individual adaptation actions can simultaneously address multiple climate-resilient development objectives. For example, in Exhibit A.1, the dam shown at the base of the mountains provides water storage (Adaptation Action 1), but may also provide structural flood protection (Adaptation Action 6) and low-emissions hydropower generation (Adaptation Action 9). Likewise, a wastewater treatment plant facility is primarily intended to protect water quality (Adaptation Action 5), but treatment processes may be energy-intensive (Adaptation Action 9), or the residuals (like methane gas) can be used to generate power (Adaptation Action 9), or wastewater can by reclaimed and reused to meet various suitable uses such as irrigation (Adaptation Action 3). Watershed protection and wetland preservation projects can likewise simultaneously protect ecosystems (Adaptation Action 8), enhance and protect water quality (Adaptation Action 5), provide non-structural flood protection (Adaptation Action 7), and enhance water storage (Adaptation Action 1). Successful implementation of any of these actions requires effective water governance (Adaptation Action 10). Therefore, practitioners are encouraged to think holistically and apply the principles of IWRM when considering which adaptation actions to evaluate as part of their efforts to promote climate-resilient development.

IWRM AND CLIMATE-RESILIENT DEVELOPMENT: INTEGRATING ELEMENTS FROM MULTIPLE ADAPTATION ACTION CATEGORIES

There are likely to be many instances when practitioners can use adaptation options drawn from many of the adaptation action categories described in this appendix. Consider, for example, the need to examine climate-related stressors on water supply and water demand in a river basin that supports a major population center as well as agricultural irrigators. Options drawn from multiple adaptation action categories may be considered and deployed as part of an integrated management approach, such as described by the following examples:

- ***Adaptation Action 1: Increase or Strengthen Water Capture and Storage.*** Increases in water storage, such as by adding or enlarging a reservoir, may be considered as a way to ensure that precipitation that falls in wet seasons (or relatively wet years) is available to meet water needs in dry seasons and drought years.
- ***Adaptation Action 2: Reduce Water Losses.*** Water pipe leak detection and repair programs might be considered to help reduce the loss of potable waters in distribution systems, thereby effectively making more water available to meet urban area needs.
- ***Adaptation Action 3: Create New Sources of Water.*** The enhanced treatment of wastewater might be considered as an option to make reclaimed water available to meet water demands for agricultural irrigation and/or and cooling at power generating facilities, thereby reducing the demands on potable supplies.
- ***Adaptation Action 4: Water Demand Management.*** Methods to conserve and make more efficient use of water in the agricultural, residential, and/or industrial sectors may be deployed as a means of meeting growing water demands without adding additional strain on the water supply.
- ***Adaptation Action 5: Protect Water Quality.*** Watershed protection efforts may be considered as a means to improve source water quality, thereby reducing the need for upgrading and expanding water treatment facilities to meet growing demands.
- ***Adaptation Actions 6 and 7: Structural and Non-structural Approaches to Flood Protection.*** The development of retention basins and other green infrastructure elements may be used to increase stormwater infiltration into local groundwater, thereby making more water available for future use (while also decreasing stormwater-related flooding).
- ***Adaptation Action 8: Protect Inland Freshwater Ecosystems and Ecosystem Services.*** Actions preserving and enhancing wetlands may be considered that will not only support important ecosystems, but will also help enhance water quality and water infiltration/storage. Such practices may be considered as part of a holistic, integrated mix of actions to help ensure future water supplies adequately meet future, climate-impacted demands.
- ***Adaptation Action 9: Manage Critical Interdependencies between Energy and Water.*** Plans to enhance power plant capacity and reliability will also enhance the ability of water systems to reliably treat and pump water to better meet future demands. And, having a more reliable water supply will likewise enhance the ability of energy facilities to produce the power needed to meet growing electricity demands.
- ***Adaptation Action 10: Strengthen Water Governance.*** How water managers choose to govern their water resources has critical influence on the sustainability, effectiveness, and practicality of any given adaptation action. Adaptation actions that strengthen water governance (e.g., decentralizing water decision-making and adopting catchment management approaches) complement and enhance other adaptation actions, such as those described above.

ADAPTATION ACTION 1 – INCREASE OR STRENGTHEN WATER CAPTURE AND STORAGE



Water storage is the ability to capture and store water during times of excess precipitation or stream flow, for use during times of greater need. Water storage can be a very important climate adaptation strategy as the variability and predictability of current precipitation patterns change within and across years. Storage can decrease the vulnerability of a community to short- and long-term dry periods by providing supplemental water resources that can be available when natural precipitation or stream flow is inadequate to meet demands. By making water available at times it would not be available naturally, water storage can significantly increase human welfare, agricultural yields, and economic productivity. This adaptation action focuses on options for storing water above-ground in cisterns, dams, impoundments, and reservoirs and below-ground in the soil and aquifers. The impact of storage on water quality will be discussed in *Adaptation Action 5: Protect Water Quality* and the impact on ecosystem health will be discussed in *Adaptation Action 8: Protect Inland Freshwater Ecosystems and Ecosystem Services*.

HOW CAN STORAGE CONTRIBUTE TO CLIMATE-RESILIENT WATER MANAGEMENT?

Increased water storage will likely become more important as a strategy to improve water system resilience to greater variability of intra-annual and inter-annual precipitation patterns. Water storage is already essential to meet the demand for water during dry seasons and in water-scarce regions. Climate change may exacerbate these existing challenges, lead to similar challenges in new areas (e.g., the need to expand irrigation to regions previously reliant on rain-fed agriculture), and increase the need for multi-year storage options. The resiliency that storage offers will be most apparent for poor farmers who are already struggling with variability and drought in already water-scarce regions, such as developing countries in arid and semi-arid regions with limited water resource availability.

WATER IN THE DEVELOPING WORLD

Agriculture is typically one of the largest users of water. Seventy percent of global freshwater withdrawals (80–90% of consumptive uses) are devoted to irrigation (Foley et al., 2011). Reliable access to water can often be the difference between success and failure for many farmers. Enhancing water storage can reduce concerns over variability in precipitation and stream flow, extend the growing seasons into warmer and/or drier months, improve yields, and enable farmers to grow more valuable crops.

Groundwater is often the major source of water for small and rural communities. For example, up to 80% of sub-Saharan Africa is reliant on groundwater as their primary or only source of water (MacDonald and Calow, 2009). Over-extraction of groundwater can lead to lowering of the water table, which in turn can have impacts such as drying of wells, increased pumping costs, increased land subsidence, reduced flows into streams and wetlands, and saltwater intrusion in coastal regions. Increasing groundwater storage and recharge can be a valuable adaptation action for maintaining water levels and ensuring the quality and availability of water for current and future uses.

Water storage options will thus be valuable parts of an effective adaptation strategy for many reasons. Storage can ensure that water is available for a wide variety of uses when seasonal and inter-annual precipitation patterns change and as demands increase. Storage can help sustain essential economic and environmental sectors, including household and municipal consumptive use, agricultural irrigation, power generation, industrial uses, and ecological services. Storage not only can enhance the quantity of water available, but it can also protect and enhance the quality of water, such as when groundwater recharge is used to help protect coastal aquifers from saltwater intrusion from sea level rise.

Exhibit A.1.1 summarizes some of the key ways that water storage can help contribute to climate-resilient water management.

EXHIBIT A.1.1. HOW WATER STORAGE OPTIONS CAN AID IN CLIMATE-RESILIENT WATER MANAGEMENT.

Climate change impact	Benefits from water storage
Higher temperatures	• Increased evaporation and reservoir depletion will decrease water availability. A broader portfolio of storage options can help to limit water shortages. • Faster snow melt will decrease summer streamflows in mountain-fed catchments. Added storage can help ameliorate water shortages during summer low flows.
Reduced precipitation or increased lag time between storm events	• Longer dry periods will require added storage to meet demand. • Collecting and storing available precipitation will minimize impacts of reduced precipitation.
High-intensity storms	• Shorter, high-intensity storms will not recharge groundwater effectively; enhanced surface and artificial recharge of groundwater can make up for reduced groundwater stocks. • Storage in reservoirs has a co-benefit of reducing peak flood flows, potentially mitigating damage from extreme events.
Sea level rise	• Salinization of coastal aquifers may necessitate increased freshwater storage in surface structures and impoundments. • Enhanced aquifer recharge and storage near coastal zones can help to limit saltwater intrusion from sea level rise.

WHAT ARE THE OPTIONS FOR WATER STORAGE?

Capture and storage methods allow the user to have more control over the availability of water and can have major impacts on the sustainability of a community. Water supply enhancement such as rainwater harvesting and storage can produce higher-quality water that is better suited for human consumption than use of polluted nearby streams or lakes.

Storage requirements are needed to address:

- Short-term inter-annual variability – seasonal wet/dry patterns
- Long-term variability – multi-year droughts

Increasing water storage can also have benefits beyond increasing water supply. For example, projects that rehabilitate or protect wetlands to increase groundwater infiltration can also provide significant environmental benefits (see *Adaptation Action 8: Protect Inland Freshwater Ecosystems and Ecosystem Services*).

Storage Options

A variety of storage options exist from large regional projects (e.g., reservoirs) to simple decentralized systems (e.g., cisterns). Storage can occur on the surface in tanks, ponds, or reservoirs, or in the ground through aquifer recharge. Different types of storage include:

- ***Option A: Ponds, cisterns, and tanks***. These are often household or small community features built to capture rainwater and/or surface runoff. The simplest options are hand-dug excavations, commonly called dug-outs, which can be lined with rock, mortar, and/or polyethylene sheets to prevent infiltration. In some cases, these are covered to prevent contamination, minimize evaporation, or reduce the risk of vector-borne disease. Concrete and steel tanks are options that provide more protection of the stored water.
- ***Option B: Reservoirs.*** Reservoirs are artificial lakes used for the storage and regulation of water. Small reservoirs are typically formed by constructing simple earthen dams. They tend to be shallow, with low volumes of water, which can drain every year with use. Larger reservoirs may be formed by constructing a dam across a stream, river, or drainage system. Natural lakes and wetlands can be modified or enhanced to improve the ability to store water. Of all the water storage options, large reservoirs are typically the most controversial due to associated social and environmental costs (IWMI, 2009). In addition to providing supplies for downstream urban uses, large reservoirs may also support agriculture, meet industrial needs, generate hydropower, and contribute to effective flood control. Some provide multi-year carryover of water and can be particularly important in addressing prolonged dry periods. Reservoirs may also be used to provide releases to enhance in-stream flows for ecologic purposes during periods of low flow and high temperatures.
- ***Option C: Soil moisture.*** Water may be stored in the soil for agriculture. Approaches such as terracing (i.e., cutting a sloped surface into a series of graduated flat surfaces or steps) or mulching can keep moisture in the soil for longer periods and increase the water availability for crops. Wetland preservation and watershed protection measures can also help preserve water in the soil.
- ***Option D: Groundwater recharge*** (also called groundwater banking, and aquifer storage and recovery). In some cases, aquifers have the capacity to store additional quantities of water. A major advantage of storage in the ground is that there is little or no evaporation. Additionally, groundwater infiltration may help to improve water quality and reduce water treatment costs later on. Even minor civil engineering works (e.g., building simple mounds along contours in fields or simple structures to slow runoff) can increase infiltration, and make water available longer into the dry season. In simple applications, old and abandoned wells can be used for recharging water. New wells can also be drilled or dug for this purpose. Infiltration basins, consisting of a shallow pond with a permeable bottom (i.e., sand), can be designed to promote infiltration in aquifers.

As shown in Exhibit A.1.2, there are trade-offs between the amount of storage provided and the complexity and cost of implementation. For example, soil moisture improvements can be easily implemented but will only provide a small amount of storage. Large reservoirs are the most complex and expensive but provide a large amount of storage. Developing a sustainable solution requires balancing the amount of storage needed with the resources available for implementation.

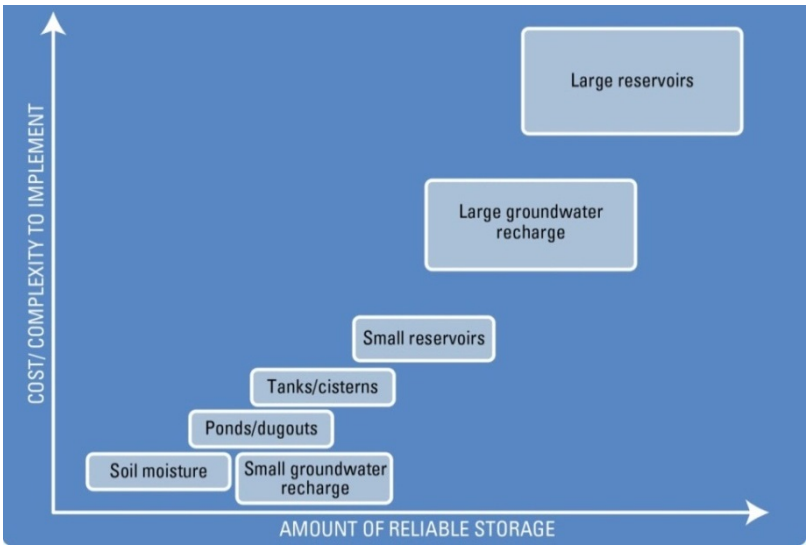


EXHIBIT A.1.2. COMPARISON OF STORAGE OPTIONS.

Approaches to Support Storage

Other techniques can be used to support storage by either directing the flow of water or improving the quality of water to protect storage systems. These include:

- ***Rainwater harvesting.*** The small-scale collection and storage of rainwater for domestic and agricultural purposes. Roof catchment systems are by far the most common form of rainwater harvesting, although in many developing countries rainfall runoff is also collected from ground or rock surfaces (Sutherland and Fenn, 2000). In the Marshall Islands, an airport runway is being used as a large-scale rainfall capture system (see example text box "Capturing airport runway runoff"). The most important factor in enhancing rainwater harvesting in rural areas is the shift away from the use of traditional roof materials such as grass thatch and dried mud to more impervious roofing materials such as metal and ceramic tiles.
- ***Land use practices and management practices.*** Reduce runoff of sediment into water supplies (sedimentation), which would reduce storage capacity in downstream reservoirs. A variety of watershed protection techniques may be employed to reduce sediment loss from agriculture, timber operations, and construction. Afforestation and reducing deforestation can increase infiltration and therefore increase groundwater recharge. Wetlands can also be used to promote infiltration and to mitigate against floods. See *Adaptation Action 7: Non-structural Approaches to Flood Protection* for more information on land use and watershed protection practices.
- ***Reducing demand.*** The need for water storage can be decreased by reducing the demand for

CAPTURING AIRPORT RUNWAY RUNOFF

A rainfall catchment system in the Marshall Islands captures rainfall in the middle section of the runway and sand-covered areas adjacent to the middle of the runway. This system was designed and installed by the U.S. Army Corps of Engineers and uses the airport's runway as a large catchment area. The catchment has an area of around 88 acres and could theoretically yield about 2.4 million gallons of water for every inch of rainfall (assuming 100% collection efficiency). Water from the airport catchment is pumped to nearby reservoirs with a total storage capacity of 38 million gallons. Water from six of the reservoirs is filtered through two large sand filtration systems and chlorinated. This water is pumped to a seventh reservoir that has a floating cover (USAID, 2009).

water resources. As discussed in *Adaptation Action 4: Water Demand Management*, water conservation and improvements in water-use efficiency can decrease demand and therefore reduce the need for water storage or extend the effectiveness of existing storage. Reducing water losses (as discussed in *Adaptation Action 2: Reduce Water Losses*) can also improve the effectiveness of water storage.

Quantity of Storage

The amount of storage per capita varies substantially between different nations (see Exhibit A.1.3). Vast water storage projects in the arid western United States, for example, have enabled agriculture in the region to become some of the most productive crop lands in the country. In contrast, Ethiopia has very low storage capacity and therefore many farmers are heavily reliant on rain-fed subsistence agriculture. It has been estimated that the lack of water storage costs Ethiopia one-third of its economic growth potential (IWMI, 2009).

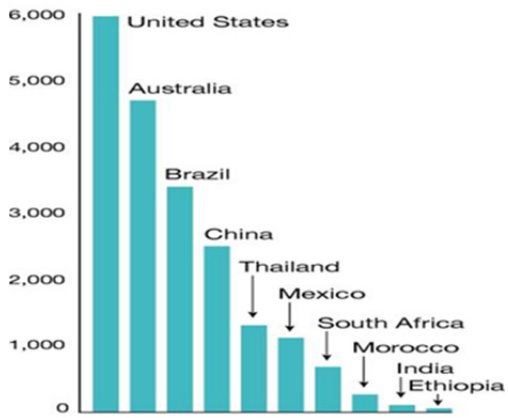


EXHIBIT A.1.3. CUBIC METERS OF STORAGE PER CAPITA.
Source: Grey and Sadoff, 2006.

The need for water storage is dependent on the availability of renewable water supplies, the demand on these water supplies, and the period of time when demand exceeds supply. Water storage to address intra-annual variability (e.g., wet/dry seasons, monsoons) is often accomplished through decentralized systems like rainwater harvesting, ponds, tanks, and small reservoirs. Accounting for longer-term, multi-year variability typically requires centralized projects like large reservoirs and groundwater recharge to meet multiple-year water supply deficits. Note that changes in climate variability may impact the duration and timing of when demand exceeds supply.

Water storage can also address concerns related to uneven spatial patterns of water availability by capturing water where it is available and transferring it to areas with limited water supplies. For example, water captured in a reservoir can be pumped large distances through canals or pipes to support agriculture and communities without adequate access to water resources. Water can also be captured in high-elevation areas, where cooler temperatures limit evaporation, and then transferred downstream (or downhill through pipes or diversions) for low-altitude uses. Both of these processes can be energy-intensive and/or lead to significant water losses from leakage or evaporation during transport. However, construction

Increased storage can be accomplished by:

- Developing new storage options
- Better managing existing storage to decrease evaporation, reduce water losses, or prevent siltation

of these conveyance structures means that water storage need not be entirely in areas where the water will eventually be used.

Under climate change scenarios, the variability of both intra-annual and long-term precipitation patterns may increase, increasing the need for more centralized storage to account for extended periods of drought. Failure to capture sufficient water resources and to plan for these events could have significant health, agriculture, and/or economic consequences.

Concerns with Water Storage

An important factor when considering water storage projects is the potential impact on downstream users. This may not be a concern in areas where there are distinct wet and dry periods and the volume of water is much greater than can be captured. However, in areas with limited precipitation, the capture of water (and therefore withdrawal from streams and rivers) can have a major impact on downstream users.

Large reservoirs are especially controversial for their wide-ranging social and environmental impacts. These impacts can range from displacing current populations and settlements, inundating cultural and natural resources, to significantly altering the local and regional environment. Reservoirs also increase evaporation and can reduce water quality in the stored and downstream waters.

Groundwater recharge projects are designed to raise the water table, which can lead to water surfacing in new areas if the projects are not well designed. This can lead to increased flows into wetlands and other low-lying areas. Another challenge with groundwater recharge is being able to withdraw the water when needed. Groundwater may flow out of the areas accessible by wells and therefore become unavailable for use. Recharging groundwater may change water quality by mobilizing contaminants such as arsenic and other contaminants present in the ground.

Water quality can also degrade over time during surface storage. Capturing more surface rainfall runoff comes with the possibility of capturing more pollution such as fertilizers, pesticides, mining/industrial/chemical wastes, and other potential sources of contamination. Furthermore, pathogenic organisms can grow if water is not properly disinfected, and standing water can be a breeding ground for mosquitoes and other insects that can spread disease within the community. Additionally, uncovered water sources attract humans, livestock, and other animals, whose presence and use can further degrade water quality.

Co-benefits of Storage

In addition to improving the reliability of water supply, storage can lead to other community benefits, including:

- ***Improved health.*** Storage can allow for better management and treatment of water, leading to water that is better suited for human consumption than water from nearby streams or lakes that may be polluted. Small-scale, decentralized approaches such as rainwater captured in cisterns and small ponds or dugouts can minimize the need to transport water, thereby greatly reducing the amount of time and level of effort required to obtain water when local sources of water are not available.
- ***Economic benefits.*** Storage can have significant economic benefits. For agriculture, yields can be improved, growing seasons can be extended into warmer and/or drier months, and more valuable crops can also be supported. Reservoirs also can be sources of hydropower. In addition, a reliable source of water can better support industry and aquaculture.

- ***Improved safety/security.*** Reservoirs can be used to provide flood protection. Management of dam releases increases the control of water supplies and downstream flows, thereby improving the security of downstream communities.
- ***Environmental benefits.*** Water storage can support wetlands, wildlife, and ecosystems. Reservoirs can provide opportunities for development of recreational and tourism services. Reservoirs also allow management for downstream in-stream flows. Additional environmental benefits can be found in *Adaptation Action 8: Protect Inland Freshwater Ecosystems and Ecosystem Services.*

WHAT NEEDS TO BE CONSIDERED FOR IMPLEMENTATION?

Each potential adaptation option should be thoroughly analyzed in order to select the best course of action. Typical considerations for any given adaptation option are listed in the "Adaptation options considerations" text box. Given these considerations, a mix of adaptation options may be utilized to address specific climate risks to a community, region, or nation.

ADAPTATION OPTION CONSIDERATIONS

- Benefits/co-benefits
- Cost/financing
- Effectiveness
- Feasibility
- Flexibility
- Timeframe
- Robustness to climate stressors
- Unintended costs

Flexibility is a particularly salient consideration for water storage options. Small-scale and decentralized approaches – such as the use of cisterns, small ponds, dugouts, soil moisture, and ground recharge – allow for considerable flexibility to locate them where needed, and the ability to move them as needed for changing precipitation and demographic patterns. Large reservoirs are fixed assets that require substantial investments of fixed capital and natural resources. However, large reservoirs provide important operational flexibility to control floods, maintain in-stream flows, generate hydropower, and/or improve water quality.

Exhibit A.1.4 provides a summary of some of the major implementation considerations for water capture and storage adaptation options. For each option, the table identifies key feasibility challenges in implementation; the relative cost of implementation (to other options included in the table); the level of decision-making typically involved (e.g., national, regional, or local); and other considerations including benefits, effectiveness, flexibility, unintended costs, or timeframe.

EXHIBIT A.1.4. IMPLEMENTATION CONSIDERATIONS FOR WATER CAPTURE AND STORAGE ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Ponds or dugouts	• Low level of necessary technical knowledge • Relatively easy to implement • Institutional and governance issues rarely problematic • Easily scaled to needs	• Low cost, may require significant labor • Costs associated with lining and covering • Low or no necessary planning costs • O&M are low or no cost	• Decision can be made at household/ community level • Higher-level decisions can incentivize or provide technical/financial resources	• Short-term storage • Projects can be started and completed quickly

EXHIBIT A.1.4. IMPLEMENTATION CONSIDERATIONS FOR WATER CAPTURE AND STORAGE ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Tanks or cisterns	• Relatively easy to implement • Low level of necessary technical knowledge • Institutional and governance issues rarely problematic • Easily scaled to needs	• Some costs associated with materials for the tank (cement, plastic, or stainless steel) may also require significant labor • Low planning costs • O&M costs should be considered	• Decision can be made at the household/ community level • Higher-level decisions can incentivize or provide technical/ financial resources	• Short-term storage • Projects can be started and completed quickly
Option B: Small reservoirs	• Typically requires land ownership and access • Requires infrastructure for dam and water release/transport • May require engineering	• Costs can be low to moderate depending on the amount of effort needed to prepare the site and build a dam • Small reservoirs typically use lower-cost materials for the dam such as rocks and earth • Some planning costs necessary for siting and basic engineering • Low to moderate O&M costs	• Decision typically made at the community/local government/regional government level • May need to consult with downstream water users	• Short- to medium-term storage • Selecting a site and getting approval may take time • Construction times vary based on site-specific variables
Option B: Large reservoirs	• Requires land ownership and access • Requires infrastructure for dam and water release/transport • Requires detailed engineering and often environmental, economic, and/or social impact analyses • Ancillary benefits such as flood control may increase feasibility	• Costs can be very large, especially for high-quality materials for the dam • Need to evaluate the social and environmental costs • Significant planning costs necessary for siting and sophisticated engineering • Significant O&M costs • Some opportunities for international development assistance	• Decision typically made at the regional government/national level • May need an involved process with local and regional stakeholders	• Medium- to long-term storage • Selecting a site and getting approval will take time • Community, public process will take time • Construction times vary, but are relatively long
Option C: Soil moisture	• Relatively easy to implement on a small scale, challenging to implement on a large scale	• Low costs for mulching • Higher cost and effort for terracing	• Decision can range from a community to regional level	• Can have an immediate impact and start quickly

EXHIBIT A.1.4. IMPLEMENTATION CONSIDERATIONS FOR WATER CAPTURE AND STORAGE ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option D: Groundwater recharge	• Relatively easy to implement on a small scale, challenging to implement on a large scale • Large projects require detailed studies of the geology and aquifers • Requires land for infiltration basin or injection well(s)	• Medium to high cost associated with construction of injection wells or infiltration basins	• Decision can range from a community to national level	• Medium- to long-term storage • Water can be extracted immediately as needed

REFERENCES AND RESOURCES

Paper that presents the Potential Storage Index and Water Stress Index and their application in India:

Devineni, N., S. Perveen, and U. Lalln. 2011. Columbia Water Center White Paper: Climate Variability and Water Stress in India: How Much Storage is Needed and Where? December. Available: http://water.columbia.edu/sitefiles/file/pub/Water%20stress_white%20paperCWC.pdf.

The authors analyze solutions to enhance global food security while concurrently shrinking the environmental footprint of global agriculture. Solutions explored include halting agricultural expansion, closing "yield gaps" on underperforming lands, increasing cropping efficiency, shifting diets, and reducing waste:

Foley, J.A., N. Ramankutty, K.A. Brauman, E.S. Cassidy, J.S. Gerber, M. Johnston, N.D. Mueller, C. O'Connell, D.K. Ray, P.C. West, C. Balzer, E.M. Bennett, S.R. Carpenter, J. Hill, C. Monfreda, S. Polasky, J. Rockström, J. Sheehan, S. Siebert, D. Tilman, and D.P.M. Zaks. 2011. Solutions for a cultivated planet. *Nature* 478:337–342. doi:10.1038/nature10452.

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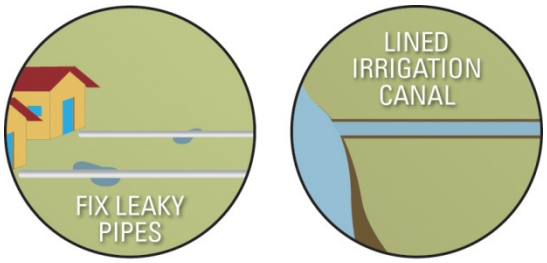
ADAPTATION ACTION 2 – REDUCE WATER LOSSES



As the demand for and value of existing water resources increases, controlling water losses and maximizing the efficiency of water use will become more important. Preventing or controlling seepage, evaporation, unauthorized water withdrawals, and waste are all methods to combat water losses from canals, reservoirs, and water distribution systems. Controlling water losses is one strategy that is often used in conjunction with developing more water storage (*Adaptation Action 1: Increase or Strengthen Water Capture and Storage*), finding new water sources (*Adaptation Action 3: Create New Sources of Water*), or making the most of existing resources through reducing demand (*Adaptation Action 4: Water Demand Management*). In many cases the strongest adaptation action will include a combination of all these actions. Note that the measures discussed often can be justified without considering climate change. The potential reductions of water supplies and the increased demand for water resulting from climate change make these measures more imperative.

HOW CAN CONTROLLING WATER LOSS CONTRIBUTE TO CLIMATE-RESILIENT WATER MANAGEMENT?

Reduced precipitation, higher temperatures, and increased variability in precipitation patterns will all require increased storage and conveyance of water to allow water to be redistributed to places and times of need. Along with this increase in active water management will be the increased potential for water losses. Reducing water losses at each step of the storage and conveyance process will ensure that a greater volume of water reaches its intended destination and end use. Each reduction in water losses results in a direct increase in available water resources for end users. For example, if water losses are reduced by 10,000 gallons/day, an additional 10,000 gallons/day will then be available for use.

WHAT ARE THE SOURCES OF WATER LOSS, AND WHAT ARE THE WAYS TO REDUCE THEM?

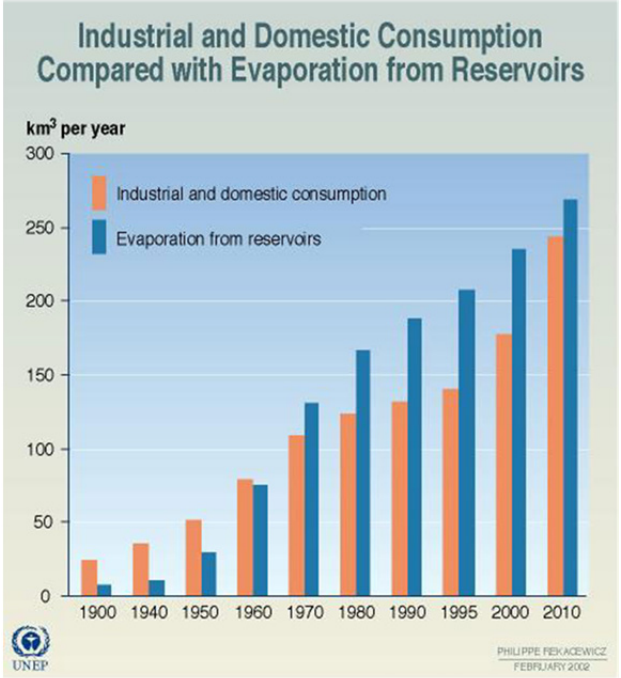
Water losses can occur during storage, in transmission in a water distribution system, through delivery to farmers in irrigation conduits and channels, or to municipal and industrial users in pipes and canals. Losses can occur through evaporation, leakage, improper operations, or through illegal or uncontrolled uses. Exhibit A.2.1 summarizes the source and causes of water losses which are discussed in more detail below. Note that the reduction of water losses as discussed here is distinct from WDM and efficiency improvements (discussed in *Adaptation Action 4: Water Demand Management*).

Sources of Water Loss

In India, the Water Management Forum (WMF) indicated that the total loss of water from large, medium, and small storage facilities to be 60,000 million m^3, which, according to the WMF, would be adequate to meet the entire municipal and rural water needs of India (Government of India, 2006). In Turkey, Gökbulak and Özhan (2006) estimated that the total evaporation loss from reservoir and lake surfaces exceeds the total annual domestic and industrial water consumption of Turkey. Rekacewicz (2005) found the industrial and domestic water consumption as a whole to be similar in magnitude to the total evaporation from reservoirs, as shown in Exhibit A.2.2.

EXHIBIT A.2.1. CAUSES AND ESTIMATES OF WATER LOSSES.

Source	Causes for water losses	Estimates of losses
Storage facilities	• Evaporation • Leakage • Consumption by vegetation	Losses greater than the total domestic and industrial uses (Gökbulak and Özhan, 2006; Government of India, 2006) Up to 50% losses in small reservoirs from evaporation; up to 25% losses from seepage (Nissen-Petersen, 2006) 6−7% consumption by alien (non-indigenous) plants (Sutherland and Fenn, 2000)
Water distribution systems	• Leaks, main breaks • Non-revenue water (NRW) – Illegal taps – Theft – Inaccurate metering	40−50% of the water produced is NRW (World Bank, 2008) NRW in Uganda ranged from 3% to 80%, with the average around 40% (Mutikanga et al., 2009)
Irrigation canals	• Leaks • Seepage • Improper operations and lack of maintenance (overflows, embankment breaks, excess plant growth)	In the Middle East, anywhere from 10% to 70% of the total volume of water conveyed through irrigation canals is lost to seepage (Goldsmith and Hildyard, 1984)



Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational,Scientific and Cultural Organisation (UNESCO, Paris), 1999.

EXHIBIT A.2.2. INDUSTRIAL AND DOMESTIC WATER CONSUMPTION VERSUS EVAPORATION FROM RESERVOIRS.

Source: Rekacewicz, 2005.

Storage Facilities

Water can be lost from storage facilities through evaporation or seepage into the ground. The amount of loss is a function of the water surface area, temperature, wind speed, barometric pressure, and geological conditions. While estimates of these losses vary substantially between countries and climates, all studies indicate that these losses are substantial and will increase with rising temperatures.

In *Water from Small Dams* (Nissen-Petersen, 2006), it was proposed that about 50% of the water in small reservoirs is lost each year to evaporation. While seepage loss is difficult to estimate because reservoirs are built on various soil types, seepage losses can account for up to 25% of the water in the reservoir. Therefore, without adequate protection, up to 75% of the water stored in a small reservoir may be lost due to evaporation and seepage losses.

Vegetation can also be a significant source of water loss. For example, in South Africa, invasive plant removal has been used to increase water in storage facilities. It has been estimated that these non-native plants remove approximately 6–7% of the total amount of water that would otherwise be available (Sutherland and Fenn, 2000).

Water Distribution Systems

Water can be lost in transmission to consumers through leaks or breaks in water lines. The American Water Works Association (AWWA) and International Water Association (IWA) published guidelines that describe water loss in terms of NRW (AWWA, 2009). NRW is comprised of:

- Unbilled authorized consumption – metered or unmetered water use that is not billed (e.g., water drawn from a hydrant by firefighters, water used by city hall that is not billed)
- Real losses – leaks, breaks, overflows from storage
- Apparent losses – unauthorized consumption (e.g., theft from hydrants, illegal taps), meter inaccuracies, or errors in data handling and billing

The World Bank (2008) stated that "a major challenge facing water utilities in the developing world is reducing water loss caused by leakage, theft, and improper billing. A high level of NRW normally indicates a poorly run utility that lacks technical and managerial skills." Aging infrastructure, inadequate operations, and maintenance are some additional causes.

IMPROVING WATER DISTRIBUTION IN ETHIOPIA

Nearly 50% of the water produced in Addis Ababa, Ethiopia was lost in the distribution system (Desalegn, 2005). After a study was conducted to characterize the causes of losses, recommendations for improvement included:

- Update existing network data
- Set performance indicators of water loss and leakage
- Address need for zoning and district meter reading
- Establish pressure management
- Regularly inspect the water network
- Properly maintain and renew networks

CANAL IMPROVEMENT ENSURES IRRIGATION IN QARGHAEE DISTRICT

With support from the USAID in Afghanistan, the newly rehabilitated Nahre Karim canal will now irrigate 2,000 ha of agriculture land benefiting 4,250 families in the Qarghaee District of Laghman Province.

The improvements included constructing a 2,910-m retaining wall, installing 24 small and 3 large water distributors, constructing 3 culverts to facilitate the easy transportation of agriculture products, and improving 4 older passages to avoid flood damage to the canal.

The canal improvement has ensured the irrigation of land that previously had limited access to water. By preventing water loss, an additional 100 ha of land at Ahmadzai Village that completely lacked water in the past has now become irrigated.

Source: USAID/Afghanistan, 2011.

The World Bank estimated that 40–50% of the water produced in developing countries is NRW (GIZ and VAG, 2011). Mutikanga et al. (2009) estimated the average NRW in Africa, Asia, and Latin America and the Caribbean to be 39–42%. They compared this to the United States with a 15% average NRW. In one study in the City of Kampala, Uganda, they estimated NRW to be 40% of water produced, with real losses from leakage about 18%, meter inaccuracies about 12%, and theft about 9%. Within Uganda the range was 3% to 80%. In Tanzania, water unaccounted for in urban centers dropped from 50% in 2000 to 41% in 2006 after the institution of a program to address leaks (Mwandosya, 2008).

Illegal water taps in Nairobi.

Photo credit: Victoria Hickman, University of Cambridge.

Irrigation Canals

Significant amounts of water can be lost in irrigation canals through seepage, leaks, or evaporation. Since agriculture accounts for up to 70% of water usage in developing countries, water losses in irrigation canals can have significant impacts on total water availability. Water loss is a function of climate, soil type, and travel distance. O&M also have a significant impact on the efficiency of use.

A study by the International Commission on Irrigation and Drainage reported that between 13.1% and 19.2% of the water transported along India's Upper Bari Doab Canal was lost to seepage. In the plains of Uttar Pradesh and the Punjab, such losses were as high as 36%. In Egypt, during the summer, the main irrigation canals are estimated to lose some 1.5 billion m^3 of water through seepage every year – approximately 10% of the water available for irrigation. Over the entire irrigation system, losses during conveyance, to seepage, and extravagance in water utilization amount to 17% of the water delivered. In many areas of the Middle East, between 10% and 70% of the total volume of water conveyed through irrigation canals is lost to seepage (examples from Goldsmith and Hildyard, 1984).

In large irrigation schemes more water is lost than in small schemes, due to the longer duration of exposure to evaporative and leakage losses (FAO, 2011). Canals in sandy soils lose more water than canals in heavy clay soils. Poor maintenance of irrigation canals will also result in greater losses relative to canals that are more actively maintained. Losses are significantly reduced when canals are lined with bricks, plastic, or concrete, although these strategies can be costly to implement. Exhibit A.2.3 provides conveyance efficiency values based on the length of the canals and the soil type in which the canals are dug. The level of maintenance is not taken into consideration; poor maintenance may lower the values in Exhibit A.2.3 by as much as 50%.

EXHIBIT A.2.3. INDICATIVE CONVEYANCE EFFICIENCY VALUES FOR ADEQUATELY MAINTAINED CANALS.

Soil type	Earthen canals			Lined canals
	Sand	Loam	Clay	
Canal length				
Long (> 2,000 m)	60%	70%	80%	95%
Medium (200–2,000 m)	70%	75%	85%	95%
Short (< 200 m)	80%	85%	90%	95%
Source: FAO, 2011.				

Reducing Water Losses from Specific Sources

Option A: Reducing Storage Facility Losses

Water losses from storage facilities are largely a function of the reservoir surface area, temperature, wind speed, barometric pressure, and geological conditions. Many of these factors can be controlled, and a variety of techniques can be employed to reduce water losses. These include:

- Providing tree cover to shade the reservoir
- Using deeper reservoirs or underground water storage to minimize the exposed surface area
- Using vegetation or wind fences to reduce evaporation from wind
- Adding a cover to reduce evaporation
- Using chemical water evaporation retarders (Government of India, 2006)
- Lining the reservoir to reduce seepage

In each case there are tradeoffs between costs and resources required. Covering or lining is most feasible for small storage facilities. Site selection is the most important factor for large reservoirs to allow for deeper reservoir and/or geology that will minimize seepage.

Option B: Reducing Water Distribution System Losses

Identifying the sources of water loss is the first step in reducing distribution system water losses. The AWWA (2009) M36 manual provides a step-by-step procedure for conducting a water audit and implementing a water-loss control program. Once sources of NRW are identified, solutions can include active leak detection programs, identifying and reducing illegal taps, or installing or calibrating water meters. A good case study in Kampala, Uganda can be found in Mutikanga et al. (2009).

Reducing leaks and main breaks is often a function of the condition of the pipe network and, therefore, rehabilitation and replacement of water mains are needed. Development of an "asset management" strategy is often necessary to effectively maintain and improve existing water delivery infrastructure.

Option C: Reducing Irrigation Canal Losses

Water losses in irrigation canals are a function of seepage, evaporation, and waste through improper operation. In most cases, improved O&M can lead to a significant reduction in water losses. This includes addressing leaks and wall breaks, dredging and removing obstructions in flow, and reducing theft from canals. Although lining canals can significantly reduce water losses, it is rarely done due to cost considerations.

Co-benefits of Reducing Water Losses

In addition to making more water available for valued end uses, there are often important co-benefits from reducing water losses. For example, reducing the amount of water lost in transmission will mean that less water needs to be pumped in order to deliver the desired volumes to the user location. Reduced pumping typically results in considerable energy savings, which in turn provides lower energy costs, lower demands on the energy resources, and reduced emissions of GHGs (see *Adaptation Action 9: Manage Critical Interdependencies between Energy and Water* for a detailed discussion of the water-energy nexus).

In addition, leaks in water distribution systems provide a pathway for pathogens and other contaminants to enter potable water supplies, creating a health risk to the water-consuming public. Leaks can reduce the water pressure at hydrants, inhibiting fire protection. Large-scale leaks may also cause water tables to rise, and this may cause damage to building foundations and other critical infrastructure. Likewise, this may create seepage areas where mosquitoes and other disease-spreading pests may breed. Thus, finding and repairing distribution system leaks will provide for improved protection of public health, property, and community welfare.

WHAT NEEDS TO BE CONSIDERED FOR IMPLEMENTATION?

Each potential adaptation option should be thoroughly analyzed in order to select the best course of action. Typical considerations for any given adaptation option are listed in the "Adaptation options considerations" text box. Given these considerations, a mix of adaptation options may be utilized to address specific climate risks to a community, region, or nation.

ADAPTATION OPTION CONSIDERATIONS

- Benefits/co-benefits
- Cost/financing
- Effectiveness
- Feasibility
- Flexibility
- Timeframe
- Robustness to climate stressors
- Unintended costs

Controlling water losses from storage facilities, within water distribution systems, and in irrigation canals each have their own implementation considerations. All start with understanding the causes for the water losses and developing targeted strategies to address specific issues. An important consideration for implementation is the value of the water saved compared to the cost of the strategy to reduce losses. In some cases, it may not be cost-effective to implement water loss mitigation strategies under current climate conditions. As climate change affects the availability of existing water resources, the value of water is likely to rise, which increases the economic benefit of strategies to reduce water losses.

Implementation Considerations for Storage Facilities

In reservoirs, the main challenge in reducing water losses is controlling evaporation and losses from seepage into groundwater. In small reservoirs, providing shading and/or wind fences are low-cost ways to reduce evaporation. Covers and lining to reduce seepage are more expensive, but can further reduce water losses. In large reservoirs, many of these strategies become impractical due to scale and associated costs. In this scenario, controlling water losses is most effectively accomplished through site selection, design, and operation of the reservoirs.

Implementation Considerations for Distribution Systems

Water distribution networks are challenged with aging infrastructure, limited resources for O&M, and limited control of unauthorized access. Addressing water losses in distribution networks requires both improving O&M and replacing aging infrastructure.

High costs for rehabilitation and replacement often lead to infrastructure operating long past expected lifetimes, with associated large water losses. Replacing aging infrastructure requires an ongoing commitment and significant investments.

The AWWA/IWA water loss protocol (AWWA, 2009) highlights the importance of a structured program to reduce sources of NRW (see Exhibit A.2.4). Emphasis on addressing NRW is needed to raise revenues to support replacing and improving water conveyance infrastructure. Under conditions that limit the availability of water resources, and potentially increase the value of water, thinking in terms of revenue lost can increase motivation to reduce water losses.

- Governance and tariffs must be tackled first
- Leak detection equipment comes last, not first
- Repair visible leaks
- Make utility staff responsible for small zones (caretakers)
- Properly meter all production and consumption
- Add district metering
- Provide good performance incentives for utility staff
- Explore links to water vendors

EXHIBIT A.2.4. PRIORITIES FOR REDUCING NRW.
Source: Frauendorfer and Liemberger, 2010.

One of the challenges in addressing water losses in the distribution system is obtaining the needed data. Leak surveys and inspections are needed to identify water losses and illegal taps. Accurate water meters on production and customers are the backbone in obtaining the data to identify water losses.

Implementation Considerations for Irrigation Canals

Controlling seepage through lining is an effective strategy to reduce water loss in canals. The most efficient and expensive strategy is to install a concrete lining. The least-expensive option is a process known as "collimation," which involves sealing porous soils with small soil grains that enter the pores during watering. However, few irrigation canals are ever lined due to the expense involved. Even lined canals can experience significant water losses without proper O&M practices.

Exhibit A.2.5 provides a summary of some of the major implementation considerations for options to reduce water losses. For each option, the table identifies key feasibility challenges in implementation; the relative cost of implementation (to other options included in the table); the level of decision-making typically involved (e.g., national, regional, or local); and other considerations including benefits, effectiveness, flexibility, unintended costs, or timeframe.

EXHIBIT A.2.5. IMPLEMENTATION CONSIDERATIONS FOR WATER LOSS CONTROL ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Reducing storage facility losses				
Small reservoirs (shading, wind fences, covering, lining)	• Low level of necessary technical knowledge • Relatively easy to implement • Institutional and governance issues rarely problematic • Easily scaled to needs	• Low cost, may require significant labor • Costs associated with lining and covering • Low or minimal planning costs • O&M are low or no cost	• Decision can be made at household/ community level • Higher-level decisions can incentivize or provide technical/financial resources	• Projects can be started and completed quickly
Large reservoirs (siting, design, operations)	• Difficult to reduce water losses from existing large reservoirs • Requires technical understanding to modify operations strategies • Requires technical understanding and engineering to improve design of new facilities	• Revising operations can have significant costs on other water users (e.g., power, recreation, in-stream flow) • Reservoir modifications will require significant capital costs	• Decision typically made at regional to national government level • May need to consult with other water users and stakeholders	• Operations changes can be implemented relatively quickly once a strategy has been approved • Reservoir modifications will take significant time to implement
Option B: Reducing water distribution system losses				
NRW (controlling real-losses through infrastructure repair and replacement)	• Readily apparent leaks/breaks can be repaired quickly, often with existing resources • Leak detection program can be done by existing personnel or by an outside contractor • Infrastructure replacement strategies will require planning, design, and engineering	• Addressing apparent leaks and leak detection programs require labor and some capital costs; payback can be achieved by reducing the amount of water lost • Infrastructure repair and replacement programs require long-term financial commitments	• Decision typically made at the community/local government/ regional government level • Higher-level decisions can incentivize or provide technical/ financial resources	• Addressing leaks/breaks is often a short-term, emergency action • Leak detection programs should be conducted on a routine basis (e.g., once every year, part of the system each year) • Infrastructure replacement strategies require a long-term, continuous commitment

EXHIBIT A.2.5. IMPLEMENTATION CONSIDERATIONS FOR WATER LOSS CONTROL ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
NRW (controlling apparent losses from theft, meter inaccuracies, illegal taps)	• Reductions of losses due to illegal taps and theft are a function of awareness, time, and organizational commitment • Meters need to be replaced every 15–20 years	• Costs are typically associated with staff time and training • Replacing meters will have significant costs and need to be part of a long-term budgeting strategy	• Decision can range from a community to regional level • Higher-level decisions can incentivize or provide technical/ financial resources	• Programs can be implemented quickly but require continuing commitment
Option C: Reducing irrigation canal losses				
Irrigation canals (O&M)	• Improved O&M can be relatively easy to implement, but requires a commitment for long-term maintenance	• Relatively low costs • Costs directly related to the size of the irrigation network	• Decision can range community, regional, to national level	• Can have an immediate impact and start quickly
Irrigation canals (lining or covering)	• Large projects that require design and engineering	• Moderate to high costs	• Decision can range from a community, regional, to national level • Higher-level decisions can incentivize or provide technical/financial resources	• Conducted as a discrete project; time is related to the size of the irrigation network, method of construction, and resources committed

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ADAPTATION ACTION 3 – CREATE NEW SOURCES OF WATER

New and additional sources of water will be needed as climate impacts the availability and reliability of existing water sources. Options such as rainwater harvesting, grey water recycling, wastewater reuse, and desalination can increase water supply by taking advantage of water that was previously considered unusable. Short- and long-term droughts, increased demand, changes in water quality, and higher water losses will increase pressures on many existing water resources. Extreme events such as tropical storms or floods may make traditional water sources temporarily unavailable. New and additional sources of water will be needed to provide the flexibility to adapt to climate impacts.

HOW CAN NEW WATER SOURCES CONTRIBUTE TO CLIMATE-RESILIENT WATER MANAGEMENT?

As climate impacts affect water availability, water quality, and water demand, existing water resources will come under more pressure. This may cause water shortages or degrade water quality such that additional treatment is needed or other sources of water become necessary. Previously unattractive sources of water that may be of lower quality, expensive to treat, or difficult to capture will become more attractive. This will include sea/brackish water or reuse of grey water and/or wastewater.

Having new water sources in addition to existing resources will provide options to increase flexibility, resilience, and reliability in the face of climate variability and change. For example, sea water desalination is resistant to drought. Grey water and water recycling would only be impacted by drought if the drought leads to a decrease in household usage of water (e.g., water conservation efforts that target irrigation would not impact quantities available for grey water and recycling).

New and/or additional sources of water can provide benefits by helping developing nations:

- ***Cope with increased variability of supply.*** With precipitation patterns becoming more variable under climate change, diversification of water resources will provide more management options to cope with changing conditions. For example, groundwater systems may react much more slowly to drought than surface waters, but may have reduced recharge if precipitation becomes more intense. Supplementing a surface water supply with groundwater (or vice versa) could be a valuable approach in some settings to diversify the local or regional water supply portfolio.
- ***Increase the ability to meet demand.*** Where demand increases due to climate impacts (e.g., because of lower precipitation and/or higher temperature) or because of non-climate stressors (e.g., increasing populations or economic growth), additional sources of water will be needed.
- ***Reduce the pressure on existing surface and groundwater resources.*** Alternative water sources can reduce demand and reliance on existing water resources, which may be stressed because of climate or other reasons (e.g., population and industrial growth). For example, if grey water is used for household irrigation, that amount of potable water would be available for consumptive or other potable use.
- ***Improve resilience to decreasing water quality.*** Climate impacts are projected to have an adverse impact on water quality. Higher temperatures, lower flows, increased pollutant concentrations, and increased runoff during extreme events can degrade water quality. Additional water sources provide options to replace degraded sources or to better match source water quality to various intended uses.

WHAT ARE THE OPTIONS FOR NEW WATER SOURCES?

New sources of water may include purchasing and importing water from another region, leveraging water sources that have typically been thought of as low value or not having the appropriate quality, or using water sources requiring treatment that are currently considered too expensive. For example, in coastal regions, water sources may have high concentrations of salts, making them non-potable water sources. While desalination is a relatively expensive option compared to current supplies, as demand and the subsequent value increases, it may become a more economically viable option (particularly compared to the alternative of facing extensive water shortages in the future).

This adaptation action focuses on exploiting existing underutilized resources. This may be accomplished by capturing rainwater or stormwater, reusing grey water or wastewater, treating sea water or brackish surface- or groundwater, or treating other water with poor quality. These actions should be undertaken in conjunction with actions to maximize existing water use through reducing water losses (*Adaptation Action 2: Reduce Water Losses*) and conserving water (*Adaptation Action 4: Water Demand Management*).

Option A: Rainwater and stormwater capture. Since most of the precipitation that falls on impermeable surfaces is lost through evaporation or runoff into surface water, rainwater and stormwater capture can significantly increase the amount of water available to a community. This can be accomplished through:

- Harvesting household-based rooftop rainwater into cisterns or other tanks
- Collecting water in small ponds or dugouts (lined or unlined)
- Recharging groundwater through infiltration or directing water down an unlined well

These small rainwater and stormwater harvesting options are especially important in arid and semi-arid regions where what little rainfall is received typically arrives in intense storms. These options can be spatially distributed and used to store water; this is particularly important for areas not connected to water infrastructure (see *Adaptation Action 1: Increase or Strengthen Water Capture and Storage*). Rainwater harvesting projects can be conducted by an individual, community, region, or nation. In developing countries, rainwater harvesting is often used for potable water uses, while in wealthier regions it is typically collected for non-potable uses such as agriculture.

Option B: Grey water recycling. Grey water comes from domestic activities such as washing clothes, washing hands, and bathing. Discharges from kitchens and dishwashing are sometimes included as grey water, but most commonly are classified with wastewater. Grey water typically receives minimal treatment and is not suitable for potable water consumption. It typically is used at or near the point of generation for irrigation or other non-potable water applications such as toilet flushing. Since application typically occurs on or near the point of generation, minimal infrastructure is required.

Option C: Wastewater reuse. Wastewater reuse (also referred to as water reclamation or water recycling) occurs when domestic wastewater is collected, treated to a level suitable for an intended

GREY WATER IN JORDAN

A project sponsored by the International Development Research Center in Canada (Al-Beiruti, 2004) demonstrated the application of household-based grey water treatment technologies in Jordan. Two-barrel and four-barrel approaches were demonstrated. In the two-barrel approach, one barrel was used to separate components that float (i.e., fats and oils) from those that sink. The second barrel was used to store the separated water. In the four-barrel approach, two barrels are added in the middle and filled with gravel to provide filtration. The resulting water was used in a drip irrigation system for watering olive trees. Domestic water consumption was shown to decrease by 30% as a result of the grey water system.

application (e.g., irrigation), and then used. The level of treatment needed varies and is based on the requirements of the application. Types of reuse include:

- ***Non-potable reuse*** is applicable for irrigation and use by industry (e.g., cooling, cleaning, manufacturing processes). Higher levels of treatment are needed for the irrigation of crops that are directly consumed by humans (e.g., fruits and vegetables).
- ***Indirect potable reuse*** is where treated wastewater is discharged to a surface water or groundwater source and mixed with natural waters that ultimately are used as a source of potable supplies. "Unplanned" indirect potable reuse occurs worldwide wherever wastewater (treated or otherwise) enters a water body that is also used as a potable supply (e.g., downstream). "Planned" indirect potable reuse typically entails providing sufficient treatment to the wastewater effluent so that it can be safely discharged to reservoirs, aquifers, or other water bodies where potable use is clearly intended, and is an intentional effort to safely enhance the local water supply. Planned indirect potable reuse is becoming more prevalent in developed nations (including the United States).
- ***Direct potable water reuse*** is when wastewater undergoes substantial treatment and is safe for immediate potable use. With advances in treatment technology and growing needs for potable supplies, direct potable reuse is being implemented in more locations, including Namibia, Singapore, and drought-impacted Texas in the United States (see the text box "Reclaiming water in Namibia and Singapore"). It still faces substantial challenges with public perception.

RECLAIMING WATER IN NAMIBIA AND SINGAPORE

Regular droughts, increasing population, and a continuous shortage of potable water supply motivated the City of Windhoek, Namibia to reclaim water (Lahnsteiner and Lemper, 2005) through a direct potable water reuse system. To accomplish this they constructed an advanced water reclamation plant in 2002. The plant uses five treatment barriers that include enhanced coagulation, ozonation, biological active carbon, granular activated carbon (GAC), and ultrafiltration. As a final barrier, reclaimed water is blended with treated dam water and/or groundwater. The maximum portion of reclaimed water fed into the distribution system is 50% in times of low-water demand (i.e., winter season). To increase both the level of awareness to water savings and the acceptance of direct potable reuse, the city developed education programs in schools, on the radio and television, as well as in printed media. An indication for the trust in potable reuse is the fact that only 5% of the population uses additional point source treatment in their homes, e.g., with GAC filters and cooling the filtrate in refrigerators.

Direct potable water reuse is practiced in Singapore and called NEWater. "It is produced from treated used water that is further purified using advanced membrane technologies and ultra-violet disinfection, making it ultra-clean and safe to drink" The first NEWater plant opened in 2003 and currently meets 30% of the nation's water needs. By 2060, NEWater is planning to provide 50% of the water demand (PUB, 2012).

Wastewater reuse projects require a collection system, centralized treatment, and a distribution network. An important challenge associated with water reuse is the need to keep it segregated from potable water systems, typically through a separate distribution line (commonly called purple pipe systems). Further challenges, especially in developing countries, arise from the need for sufficient water quality monitoring capacity and ongoing O&M of the reuse system to maintain necessary treatment levels.

Option D: Desalination. Over 90% of the water on the Earth is unsuitable for human consumption due to its salinity. Desalination holds the promise for virtually unlimited water resources in coastal regions. Inland

brackish water (which can be plentiful) can also be rendered suitable for potable, irrigation, and other uses when treated using desalination. Implementation of desalination technology is rapidly expanding. The most common technologies used for desalination are reverse osmosis and nanofiltration membranes. Energy-intensive thermal distillation is applied in some older generation desalination facilities (such as oil-rich regions where energy is plentiful and relatively inexpensive).

Desalination is often considered in concert with other practices such as water conservation, water loss reduction, and wastewater reuse. Because of financial costs and challenges – such as the need to dispose of brine (i.e., the concentrated salts and other elements removed from the water), energy demands, and potential impingement and entrainment impacts on fisheries where coastal water intakes are located – desalination is often considered after other options are deemed less feasible. However, with recent advances in membrane technology and energy management, desalination is becoming more economical and prevalent worldwide. It can be scaled easily to different-sized needs, and can serve as a full-time supply source or intermittently when critical water needs are identified. It also is a supply option that is not typically impacted by weather and climate conditions, and produces a fairly reliable yield regardless of precipitation patterns.

WASTEWATER RECYCLING AND DESALINATION

In the Middle East and North Africa (MENA) region, the gap between renewable water supplies and demand will grow by five-fold, from today's 42 km^3 to approximately 200 km^3 by 2050. Currently much of the demand gap is being met through the unsustainable practice of mining fossil groundwater reserves. However, without an orderly transition to more sustainable supplies, the danger remains that considerable sections of rural economies could collapse from lack of water.

Wastewater recycling is one activity that will increase over time. It could add approximately 22 km^3 a year to MENA's renewable water resources by 2030, and as much as 40 km^3 a year by 2050. This increase will be driven first by population growth, second by the extension of wastewater collection and treatment networks, and third by acceptance of its use.

Desalination has proved to be a technically feasible supply solution to MENA's water gap and will continue to do so. Desalination currently provides slightly more than 3% of the total regional water demand. Under the average climate change scenario, assuming that all viable demand and supply management measures are implemented, desalination may have to provide as much as 19% of regional water demand by 2050. The coupling of renewable energy sources with desalination has the potential to provide a sustainable source of potable water.

Source: World Bank, 2011.

Other options. A wide variety of water treatment technologies are available to make previously non-useable water sources into sources of potable water or water suitable for other targeted uses (such as irrigation or industrial use). Treatment technologies can address microbial and/or chemical contaminants. They can be applied on the community level at centralized water treatment facilities (including small-scale approaches using modular treatment units), or at the point-of-use with in-home treatment devices. Technologies are also being developed that operate using energy from renewable sources such as solar panels. An important challenge with such systems in a developing country context is that most require ongoing maintenance to ensure effective operation. In many cases maintenance can be as simple as replacing filters, clearing screens, and cleaning equipment. However, training and local capacity building are often necessary to ensure such systems work over the long-term.

Exhibit A.3.1 provides a comparison of the different options for new sources of water.

EXHIBIT A.3.1. COMPARISON OF NEW SOURCES OF WATER.

New water sources	Scale	Water source	Application	Treatment needs
Option A: Rainwater and stormwater capture	Decentralized – household to community	Precipitation on rooftops or other impermeable surfaces	Potable and/or non-potable	Treatment may or may not be required
Option B: Grey water recycling	Decentralized – household to community	Domestic (non-sewage) wastewater used for laundry and bathing; kitchen and dishwashing wastewater may or may not be considered grey water	Non-potable water (e.g., irrigation, toilet flushing)	Minimal treatment – can include separation of solids, fats, oils, and grease; filtration; and disinfection
Option C: Wastewater reuse	Community to regional – requires collection, treatment, and distribution network	All wastewater (sewage and grey water)	Non-potable, indirect potable reuse, and direct potable reuse	Advanced treatment required – type and amount varies on intended end use
Option D: Desalination	Community to regional – can be small- to large-scale	Brackish surface or groundwater and sea water	Potable water use	Utilizes membrane or thermal distillation technologies
Other options	Household to regional	Contaminated water	Potable or other water uses	Specialized treatment depending on source water quality and intended end use

WHAT NEEDS TO BE CONSIDERED FOR IMPLEMENTATION?

Each potential adaptation option should be thoroughly analyzed in order to select the best course of action. Typical considerations for any given adaptation option are listed in the "Adaptation options considerations" text box. Given these considerations, a mix of adaptation options may be utilized to address specific climate risks to a community, region, or nation.

ADAPTATION OPTION CONSIDERATIONS

- Benefits/co-benefits
- Cost/financing
- Effectiveness
- Feasibility
- Flexibility
- Timeframe
- Robustness to climate stressors
- Unintended costs

In practice, the most readily available and cost-effective water sources are typically the ones currently being used. However, existing sources may already be tapped to (or beyond) the maximum sustainable extent, or become more limited under climate variability and change. The new additional water sources discussed in this adaptation action are typically more expensive and/or challenging to implement, and therefore are often used to supplement existing resources. They may also serve small sectors that are currently underserved or challenging to supply. Rarely will these options entirely replace the existing resources; however, under climate change scenarios there may be more need to replace or supplement existing supplies.

Water quality from new sources should also be matched to the appropriate application. While fully treated potable water can be used for any application, lower-quality water (e.g., grey water or recycled water) can be

used for certain non-potable applications (e.g., for industrial and cooling processes or irrigation) without requiring extensive treatment. Caution may be necessary to ensure that people do not inappropriately use lower-quality water in ways that might endanger human health. Where it is feasible, however, the substitution of lower-quality water for appropriate uses can reduce the demand on the higher-quality water source for potable needs.

Implementation of new sources may also be affected by public perception of the different options. While water reuse is gaining acceptance worldwide, it still suffers from the "toilet-to-tap" stigma. Desalination is considered expensive and energy-intensive, and carries environmental concerns associated with the disposal of residuals and entrainment of marine organisms. Education and involvement of the public and governmental officials may be needed for acceptance, management, and governance related to these technologies.

Exhibit A.3.2 provides a summary of some of the major implementation considerations for options to create new sources of water. For each option, the table identifies key feasibility challenges in implementation; the relative cost of implementation (to other options included in the table); the level of decision-making typically involved (e.g., national, regional, or local); and other considerations including benefits, effectiveness, flexibility, unintended costs, or timeframe.

EXHIBIT A.3.2. IMPLEMENTATION CONSIDERATIONS FOR NEW SOURCES OF WATER ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Rainwater and stormwater capture	• Low level of necessary technical knowledge • Relatively easy to implement • Institutional and governance issues rarely problematic • Easily scaled to needs	• Relatively low cost, may require significant labor • Low or no necessary planning costs • Some costs associated with materials for storage tanks (e.g., cement, plastic, or stainless steel) and may also require significant labor • O&M are low or no cost	• Decision can be made at household or community level • Higher-level decisions can incentivize or provide technical/ financial resources	• Projects can be started and completed quickly • Short-term storage
Option B: Grey water recycling	• Relatively easy to implement for non-potable water applications • Institutional and governance issues rarely problematic	• Relatively low	• Decision can be made at household or community level • Higher-level decisions can incentivize or provide technical/ financial resources	• Projects can be started and completed quickly • Reduces demand on existing water resources • People may use this water inappropriately when other sources are unavailable (e.g., drinking water)

EXHIBIT A.3.2. IMPLEMENTATION CONSIDERATIONS FOR NEW SOURCES OF WATER ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option C: Wastewater reuse	• Requires wastewater collection system, treatment system, and distribution system infrastructure • Requires design and engineering	• Requires significant capital investment • Requires significant O&M • Planning costs necessary for siting and engineering	• Decision typically made at the community/local government/ regional government level	• Will take significant time to design and construct; time greatly reduced if wastewater collection and treatment infrastructure currently in place • Provides a significant new source of water for non-potable, indirect potable, or direct potable use • Not impacted by drought conditions (unless household water restrictions are implemented)
Option D: Desalination	• Requires development and installation of a treatment facility • Requires design and engineering	• Capital costs can be very large • Significant planning costs necessary for siting and sophisticated engineering • Significant O&M costs • Some opportunities for international development assistance	• Decision typically made at the community/local government/ regional government level	• Small modular systems can implemented relatively rapidly • Large community-wide system will take significant time and effort to implement

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ADAPTATION ACTION 4 – WATER DEMAND MANAGEMENT

WDM is the adaptation and implementation of a strategy or program by a water institution or consumer to influence water demand and usage. WDM is typically implemented in order to meet one or more of the following objectives: economic efficiency, social development, social equity, environmental protection, and sustainability of water supply and services. WDM can be a valuable tool for increasing resilience to climate impacts on water availability, accessibility, and quality. The WDM process is strategic in promoting and increasing water use efficiency and the use of water-saving methods and technologies in order to help reduce pressure on water resources due to population growth, intensive land use, trans-boundary water management issues, and climate variability and change.[12]

HOW DOES WDM CONTRIBUTE TO CLIMATE-RESILIENT WATER MANAGEMENT?

More frequent drought events, reduced or more variable precipitation, warmer temperatures, and greater evaporation rates will affect the availability and accessibility of water resources. Effective WDM strategies can reduce water waste, lessen the pressure placed on already limited water supplies, and sustain water resources for future use. Since WDM promotes long-term good water management practices, WDM will reduce long-term demand on scarce water resources, reducing the vulnerability of water resources to climate impacts.

KEY TERMS

Water-use efficiency is the use of less water to obtain the same level of output or enjoyment from a water application (e.g., behavioral changes).

Water consumption is the extraction of water from its source for consumption (e.g., occurs with agriculture).

Water withdrawal is the diversion or withdrawal of water from a surface or groundwater source. Withdrawn water may be quickly returned to its original source (e.g., thermal electric power plants using "once-through" cooling).

WDM is most valuable in water-stressed or water-scarce regions where water demand is high, and in sectors with high levels of water usage. Currently, almost one-fifth of the world's population (about 1.2 billion people) live in areas where water is scarce (WHO, 2012). Depending on the country and region, sectors with high water consumption or extraction may include industry, mining, tourism, urban settlements, energy, and agriculture. Agriculture is one of the largest users of water. The sector accounts for approximately 70% of global water withdrawals and 90% of global consumptive water use (IPCC, 2007). Through WDM, irrigation practices can be improved to drastically reduce water consumption and allow for the water needs of other users such as households to be met. Implementing WDM actions in sectors with the largest water demands will contribute most to water saving and efficiency, and resilience to climate impacts.

WATER SUPPLY AND DEMAND IN INDIA

In India, water supply is approximately 740 billion m^3; by 2030, water demand in the country could grow to almost 1.5 trillion m^3 due to a rapid population growth and increasing domestic demand for rice, wheat, and sugar (2030 Water Resources Group, 2009). If no action is taken to manage water demand in India, the country's water supply, which predominantly comes from the country's rivers, could diminish significantly and a water scarcity issue could arise. Due to intensive irrigation or mismanagement of irrigation systems for agricultural production, severe water scarcity issues could arise in India and elsewhere.

12. Water reuse and recycling can be categorized as a WDM option. It can also be described as the creation of a new water source. In this guide, the option will be categorized a substitute source of water that meets suitable types of demands and end uses, and will be covered in *Adaptation Action 3: Create New Sources of Water.*

WHAT ARE THE OPTIONS FOR WDM?

WDM consists of planning and controlling water distribution and consumer usage through social, economic, and technical measures in order to establish a balance between water supply and demand. These measures can include policy implementation or investments in water-saving equipment and tools. Effective short-term WDM options include temporary water use restrictions, or pricing and retrofitting initiatives; long-term options include leakage monitoring and repair (see *Adaptation Action 2: Reduce Water Losses*), and pricing structure reforms. Other WDM measures include campaigns to raise awareness of water conservation and waste minimization measures, technical standards for water-saving devices and water-efficient appliances, and policies to encourage conservation.

WDM measures can come in many forms; some can be very small scale at the household level, or can take place in schools, government buildings, hotels, or industries. Since agriculture accounts for the largest share of water demand in most countries, the greatest potential for savings comes from measures that use irrigation water more efficiently or reduce water requirements for crops. Most water-saving strategies are not capital intensive nor do they require highly advanced technology to implement. Depending on a country's financial and technological resources, climate risks, and political, economic, and social systems, some options will be more feasible and effective than others.

Option A: Improved Irrigation Techniques and Practices

This WDM strategy entails using irrigation techniques and practices that reduce the amount of water used in agriculture and landscaping. Using low pressure, low-level sprinklers; drip irrigation; and scheduled irrigation are methods that can reduce water use and evaporation, and improve water efficiency. Monitoring of soil moisture content and scheduling irrigation according to plant requirements can reduce irrigation demand substantially. The landscaping and gardening practices of Xeriscaping is also a water-saving technique that reduces water needed in irrigation and maintains consistent yields during periods of water scarcity and limited rainfall. Typically this method uses plants that are drought-tolerant or highly resistant to low rainfall to create a natural landscape (these are often native plants). Xeriscaping also consists of limiting grassy turf areas, selecting and zoning plants according to their water needs, improving drainage, and maintaining soil moisture by using water-efficient irrigation practices.

Option B: Water-saving Policies

Virtual water. Virtual water (also known as embedded or hidden water) refers to the water used in the production of a traded good or service. For example, the production of 1 kilogram of crops and livestock can require 1,000 or more kilograms of water. Producing these water-intensive products in regions with more plentiful water supplies can reduce the stress on water supplies in more arid regions. Policies that support the importation of water-intensive food and industrial products in arid areas, or the use of drought-tolerant crops in arid areas can help address water scarcity in these areas.

Example of drip irrigation.
Photo credit: Glen Anderson.

Water trading. Water trading, which consists of buying and selling access to water, can also be an effective tool for WDM. Owners of water rights

have the opportunity to trade their property rights to other potential users to use productively. Most water trading has occurred within the same sectors and between farmers. For example, farmers with water rights can switch to using water-saving technologies and high-value, less water-intensive crops, and then sell their resulting water surplus. Through this process, these farmers voluntarily use water efficiently and gain profits by selling their water surplus to individuals who may be affected by water shortages. In other cases, urban areas have purchased excess water rights from farmers to address urban needs.

An efficient, formal water market requires well-defined, enforceable, and transferable water rights. To establish an active water market, rights to water use must be authorized separately from the land. In addition, the initial assignment of water rights should be perceived as fair. Appropriate legislation must be enacted and formal institutional mechanisms at different levels must be established to govern the functioning of water markets. While water markets can function in the absence of formal water rights, the most effective markets are formalized and extend beyond small scales and local levels toward larger-scale, inter-sectoral water transfers. Countries like South Africa, Chile, India, Mexico, and Pakistan have formal and informal water trading schemes that have been in existence for decades.

Example of Xeriscaping.
Photo credit: Glen Anderson.

Design standards. For large-scale conservation initiatives, water conserving plumbing or environmentally sustainable standards can be enforced or implemented voluntarily in large buildings or throughout a community. A frequently used design standard for building plumbing in the United States is the United States Green Business Council's Leadership in Energy and Environmental Design (LEED) standards and verification. Through LEED, buildings are certified based on their efficiency, use of a point system, and strategies aimed at achieving high performance in key areas of human and environmental health. To earn LEED certification, a 20% reduction in internal building water use is required. Similarly, product labeling can help building owners, designers, and contractors select fixtures that increase water savings. One example of such product labeling in the United States is the U.S. Environmental Protection Agency WaterSense label, which guarantees a minimum of 20% water savings over traditional fixtures. In Amman, Jordan, as a result of a new advisory building code, new high-rise developments were able to have a 40% reduction in water usage and other residential areas had a 15–20% reduction in water demand (Global Water Intelligence, 2012). The travel and tourism industry also has developed internationally recognized sustainability standards that are tailored to reducing water demand, among other things. These programs include Green Globe 21, the ECOHOTEL initiative, Green Key, and the Certification for Sustainable Tourism.

Incentive programs. Incentives such as water reduction credits awarded for changes in water usage can also encourage users to save water. Consumer practices can be incentivized by utilities or governments providing rebates on purchases of devices that reduce water demand (see Option D below). This is often seen with rebates for low-flow toilets, water fixtures, and sprinkler systems. This method encourages customers to purchase these items and rewards them for reducing water demand through their installation. Incentives can also be in the form of community grants for lower-income communities to implement WDM measures. The availability of economic incentives will vary depending on an individual country's political and institutional support for reducing water usage.

Option C: Pricing and Metering

Charging consumers for their water usage from sources like pipes or tankers by using metering, water pricing, or tariffs can be an effective method to reduce water demand because it provides an economic incentive for people to use less water. Metering systems also provide essential data needed to measure consumption, detect water leakage, and charge fees based on actual usage rates. In addition to resource conservation, additional objectives of pricing and metering are revenue sufficiency, economic efficiency, system sustainability/maintenance, and equity.

Examples of pricing methods include:

- ***Flat rate fees*** are fixed fees charged irrespective of the amount of water consumed.
- ***Volumetric or tiered fees,*** which can include fees that are proportional to consumption, or fees that are increased as a block system. In a block system, the first block of water sells at a base rate (which is typically lower to protect poor households), and subsequent blocks have increasingly higher surcharges.
- ***Water surcharge pricing*** imposes a higher rate on excessive water usage and the customer pays more money for a volume of water that is considered above the average (or above a set threshold).
- ***Fees*** scaled by time-of-day, in which charges are relatively higher during peak use periods.

In developing countries, where poor populations may be unable to afford water payments, these methods may be challenging to implement. In such countries, pricing methods may be more appropriate to use for the industrial, energy, or large-scale agricultural sectors.

Option D: Retrofitting and Water-saving Devices

Water conservation can be improved by retrofitting current fixtures and appliances, or by installing new water-saving indoor and outdoor fixtures and appliances. At the household level or in buildings with flush toilets, using low-flow fixtures or dual flush toilets can lead to a 40% water savings when used properly (International Resources Group, 2007).

Faucet aerators are also water efficient as they reduce water flow, but give an impression of a strong flow; water flow can be reduced by up to 1.9 to 9.5 liters per minute with these devices (International Resources Group, 2007). In the tourism, industrial, and agricultural sectors where water demand tends to be high, water consumption can be reduced with automatic shut-off valves and through water reuse and recycling. There may also be various process changes that industries can adopt that rely on less water, so that the same level of production can be maintained at lower levels of water use input.

Retrofitting, using water-saving fixtures and devices, and implementation of environmental standards in buildings may be challenging options to use in developing countries. However, there is evidence of these options being successfully applied in some developing countries, such as India. The measures may be most appropriate to use in urban government buildings, hotels, factories, and wealthier households and communities, as these users may be more able to access and afford the costs associated with these measures.

Option E: Education and Raising Awareness

Increasing awareness of water use by educating households, schools, hotels, and communities on water-saving habits, tools, and programs can be an effective strategy for reducing water demand. In countries where water availability and conservation are limited, instilling better water-use habits into the daily practices of consumers, particularly in relation to indoor water use, can significantly reduce water demand. Long-term educational programs tend to be most effective when directed at youth who have not yet established water-using habits. Focusing on adults, however, can be equally important as they are in a better position to respond

to conservation tips, given the larger role they play in providing water in the household and consumption in other settings. Behavioral changes that can substantially reduce water demand include:

- Maintaining pipes, fixtures, and appliances to prevent leaks
- Watering agricultural products or landscaping at specific times of day or using specific techniques to reduce evaporative loss
- Using dry cleaning methods rather than water to clean indoor and outdoor surfaces
- Reducing the duration of showers and faucet use
- Shutting off faucets when brushing teeth, shaving, and washing hands

Behavioral WDM practices can be voluntarily carried out; however, in a water shortage or drought situation, mandatory use restrictions can be implemented on the total quantity of water that can be used, as well as on particular water uses, e.g., outdoors, on lawns, and car washing.

Hotels can implement water conservation campaigns that include making their guests more aware of water-saving practices and ways to take action. One common method is leaving a notice in the guestroom to notify guests that their sheets and towels will be replaced at their request, rather than daily, which helps reduce water demand from washing these items. To hotel owners and managers, the financial benefits of water efficiency are the most compelling. Conserving water in hotels reduces expenditures on water supply from local utilities and tankers. Reducing water consumption also reduces the costs associated with treating raw water, wastewater treatment systems, water storage tanks, pumps and pressure tanks, septic tanks, and other related equipment.

In considering how to present and promote water-saving options, it is important to recognize that people will often respond favorably to public restrictions and ask for water conservation during periods of water shortages. However, if water shortages are temporary, people will often revert to their previous water-use habits.

To improve the likelihood of long-lasting WDM measures, initiatives should be paired with education on the importance of water conservation, the effects of climate and non-climate stressors on water resources, and how to manage the WDM option.

WHAT NEEDS TO BE CONSIDERED FOR IMPLEMENTATION?

Each potential adaptation option should be thoroughly analyzed in order to select the best course of action. Typical considerations for any given adaptation option are listed in the "Adaptation options considerations" text box. Given these considerations, a mix of adaptation options may be utilized to address specific climate risks to a community, region, or nation.

In order to determine the most beneficial WDM measures to implement, assessments should be conducted on the cultural, physical, economic, and political context of a country or region. Among these considerations, feasibility and cost are particularly important.

ADAPTATION OPTION CONSIDERATIONS

- Benefits/co-benefits
- Cost/financing
- Effectiveness
- Feasibility
- Flexibility
- Timeframe
- Robustness to climate stressors
- Unintended costs

The feasibility of a particular strategy will depend on existing institutional capacity, political acceptability, scalability, and technical and knowledge capabilities. For example, in lower-income households, communities, and nations, more advanced and costly technologies may be unaffordable. Similarly, a lack of political will can

pose a barrier as governments must play a significant role in WDM policy development and in implementing WDM measures, particularly at a large-scale or across large sectors, like agriculture. Limited awareness and capacity often limit the feasibility of specific WDM measures at the household, community, and institutional levels.

Cost considerations should include opportunity costs, cost-benefit or cost-effectiveness analysis, and the value added per unit of water saved by one measure versus another. In urban settings, WDM measures often have benefit-to-cost ratios in excess of 10:1. Cost assessments can help identify target areas with the best value for water conservation. Relevant costs to consider include the cost of installation, O&M of new appliances or fixtures, or the cost of developing an educational program based on the size and scale of the program implementation. However, financial constraints may impair the ability to invest in and implement various WDM measures. For example, a low-cost housing project will likely utilize the cheapest toilet and tap fittings without considering the water demands of these fixtures. In addition, financial constraints of users result in an inability to afford WDM measures. In many instances, fiscal resources are not available to install water meters, which are essential to water-use pricing and associated incentives to use water efficiently.

Exhibit A.4.1 provides a summary of some of the major implementation considerations for options to reduce demand and strengthen water conservation/efficiency training, incentives, and practices. For each option, the table identifies key feasibility challenges in implementation; the relative cost of implementation (to other options included in the table); the level of decision-making typically involved (e.g., national, regional, or local); and other considerations including benefits, effectiveness, flexibility, unintended costs, or timeframe.

EXHIBIT A.4.1. IMPLEMENTATION CONSIDERATIONS FOR WDM ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Improved irrigation techniques and practices	• Requires monitoring and may require enforcement to avoid misuse • Relatively easy on small scale, will require increased efforts on a larger scale	• Drip irrigation practices and reducing water use are low cost • Other irrigation projects can be moderate to high cost depending on scale of project	• Local/national level	• Initiative can take significant amount of time to implement • Most effective in areas that have seasonal fluctuations of water or do not have a plentiful supply of water to go toward irrigation purposes

EXHIBIT A.4.1. IMPLEMENTATION CONSIDERATIONS FOR WDM ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option B: Water-saving policies	• Requires implementation, monitoring, regulation, and may require enforcement to avoid violations and a conflict resolution mechanism • Pricing of water for trading will vary by location, governing and regulatory body, and market	• Low to high depending on scale of project, country, and region • Requires planning, labor, and infrastructure	• Hotel/local level • Environmental management systems standards can be local, national, or international • Community/ local/national/ regional level	• Initiative can take significant amount of time to develop and implement • Makes hotel resources use more efficient measures, while reducing operating costs, increasing guest and staff awareness, and gaining recognition in the tourism sector • Most effective when carried out formally, at a larger scale, and when stakeholders have incentive to participate in using water efficiently
Option C: Pricing and metering	• The flat rate system is convenient in cases where metering systems are not in place – more feasible in developing countries. • All systems other than the flat rate system require a metering system – may be challenging to implement in developing countries • Requires monitoring and may require enforcement to avoid misuse or violations • Pricing or raising water prices can be difficult politically	• Low to moderate costs – the least expensive is piped water and the most expensive water is provided by point-source vendors, tanker trucks, and carters • More cost effective than non-price approaches • Costs associated with installing metering systems and monitoring • Pricing policies are typically dictated by country's laws	• Local/national government level	• Can take significant amount of time to implement and carry out monitoring activities • Billing customers based on actual consumption and creating financial incentive to change water-use practices directly reduces water use • Difficult to control and charge additional fees

EXHIBIT A.4.1. IMPLEMENTATION CONSIDERATIONS FOR WDM ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option D: Retrofitting and water-saving devices	• Implementation is easier for large-scale retrofits • In some countries, changes to water fixtures may not be possible • Requires monitoring and may also require enforcement to avoid misuse or violations	• In many cases, initial investments will be paid off and water savings realized within a short time period • In some cases, low-flow fixtures investments not worthwhile if the relative cost savings are marginal in comparison to other options • Low to high costs depending on scale of retrofitting efforts	• Household/ local/national level	• Can be implemented relatively quickly if equipment and other essential resources are available • Changing or retrofitting indoor and outdoor water fixtures has a long-lasting effect on water savings • Schools and government buildings offer great opportunity to save water due to the high use rate for individual appliance and fixtures by students and staff
Option E: Education and raising awareness	• Relatively easy to implement in various settings and communities, at small or larger scales	• Low cost • Requires planning, labor, and materials	• Household/ community/ national/ regional level	• Initiatives and programs can be started quickly and have positive long-term effects • Most effective for lower-income households for which water prices are an important cost, and economic savings can be motivators • May be less effective as a voluntary education program (in comparison to stringent mandatory policies) • Ongoing education campaigns may be necessary for long-term success

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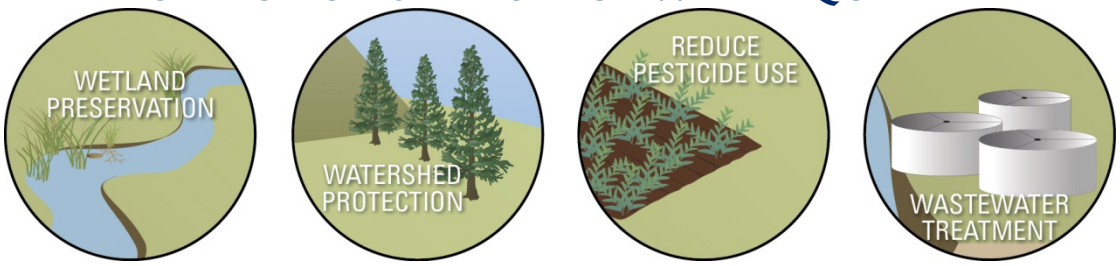
ADAPTATION ACTION 5 – PROTECT WATER QUALITY



Access to high-quality water is essential for protecting human health, economic activities, and ecological functions. Currently, obtaining high-quality water is a significant challenge in developing countries and numerous efforts are ongoing to improve delivery of safe, high-quality water. Because climate impacts are likely to exacerbate water quality challenges, this adaptation action focuses on options to improve access to high-quality water and improve the resilience of high-quality water supplies to climate impacts.

This water quality adaptation action overlaps significantly with two other adaptation actions. Water quality as it relates to ecosystem services is covered in *Adaptation Action 8: Protect Inland Freshwater Ecosystems and Ecosystem Services*. Wastewater reuse, an important action to protect water quality, is discussed in *Adaptation Action 3: Create New Sources of Water*.

HOW DO WATER QUALITY IMPROVEMENTS CONTRIBUTE TO CLIMATE-RESILIENT WATER MANAGEMENT?

Water quality is impacted by higher temperatures, which can be caused by both climate variability and change. Higher temperatures can result in reduced dissolved oxygen content, increased release of phosphorus from sediments, algal blooms, and increased bacterial and fungal content of water. Water quality in lakes is likely to be negatively impacted by rising temperatures through increased thermal stability and altered mixing patterns (IPCC, 2008). Increased temperatures can also exacerbate algal blooms, and create other temperature-related, water quality issues (IPCC, 2007, 2008).

Projected increases in heavy precipitation events can lead to more intense or frequent contamination of surface water from stormwater runoff and sanitary sewer overflows (IPCC, 2007). More intense rainfall can also exacerbate erosion and turbidity and enhance the transport of pathogens and other pollutants to surface waters (IPCC, 2008).

Reduced or less frequent precipitation, which is projected in many areas, can also have negative impacts on water quality. In areas with reduced rainfall, a decrease in stream flow may inhibit the dilution of contaminants, increasing pollutant and pathogen concentrations (IPCC, 2008). Groundwater quality may be negatively affected by climate impacts as increased evapotranspiration in semi-arid and arid regions, and sea level rise along the coasts can increase salinization of groundwater (IPCC, 2007, 2008). Exhibit A.5.1 summarizes climate impacts on water quality.

Investments in improving water quality in the developing world are cost-beneficial irrespective of climate impacts. A US $1 investment in the improvements required to halve the proportion of those without access to safe drinking water in developing regions has been estimated to produce a return of US $5–28 (Hutton and Haller, 2004). Exhibit A.5.2 presents estimated total economic benefits of improving household water quality in regions of the world facing significant water quality challenges. Worldwide, improving access to high-quality water could produce between US $18 and $556 billion in economic benefits.

EXHIBIT A.5.1. SUMMARY OF CLIMATE IMPACTS ON WATER QUALITY.

Climate impact	Water quality effect
Increased temperature	• Increased algal blooms • Reduced dissolved oxygen • Increased pathogen levels • Greater evaporation leading to concentration of salts and other pollutants
More heavy precipitation events	• Increased erosion and turbidity • Increased transport of pathogens and other pollutants • More frequent stormwater and combined sewer overflows
Decreased precipitation	• Less dilution of pollutant loads • Increased potential for wildfires, which can lead to increased sediment and nutrient loading
Sea level rise	• Increased saltwater intrusion

EXHIBIT A.5.2. TOTAL ECONOMIC BENEFITS OF INTERVENTIONS TO IMPROVE HOUSEHOLD WATER QUALITY.

Region	Population (millions)	Range of economic benefits (millions 2000 US)
Eastern and Southern Africa	481	$3,084–58,993
Central America	93	$382–9,007
Eastern Europe	223	$46–5,337
Asia (SEAR-D; includes India)	1,689	$2,201–101,643
Asia (WPR-B1; includes China)	1,488	$2,436–54,426
World	7,183	$18,143–555,901
Source: Adapted from Hutton and Haller, 2004.		

Water Quality Parameters

Water quality parameters are often measured to address regulations or guidelines that have been developed to protect public health, the environment, or support economic health. They are often compared to guidelines that are related to the potential uses or application being sustained, which can include potable water applications (e.g., drinking, food preparation, and bathing), non-potable uses (e.g., sanitation, water for industrial applications, and irrigation), and environmental uses (e.g., in-stream flows, supporting fisheries).

WHAT IS WATER QUALITY AND WHY IS IT IMPORTANT?

Water quality refers to the physical, chemical, and biological characteristics of water. It is often discussed in the context of its suitability to support or detract from a particular water use. For example, higher-quality water is required for potable uses such as drinking, food preparation, and bathing. Lower-quality water can be used for applications such as sanitation (e.g., toilet flushing), industrial cooling and processing, and irrigation for agriculture. However, the lowest-quality water may not be suitable for any use, and can lead to negative ecological and public health impacts.

Lack of high-quality water is often a significant issue for developing countries, and presents a significant risk to human health. As of 2010, 783 million people worldwide lacked access to improved drinking water sources and 2.5 billion people lacked access to improved sanitation, which can exacerbate water quality issues (WHO, 2012a). WHO estimates that 1.7 million deaths per year are caused by inadequate water supply and poor sanitation and hygiene (IPCC, 2008). See Exhibit A.5.3 for a breakdown of water, sanitation, and hygiene-related deaths by country. Climate impacts will further exacerbate these problems. Addressing water quality issues is critical to meeting Millennium Development Goal 7.C: "Halve, by 2015, the proportion of the populations without sustainable access to safe drinking water and basic sanitation" (http://www.un.org/millenniumgoals/environ.shtml).

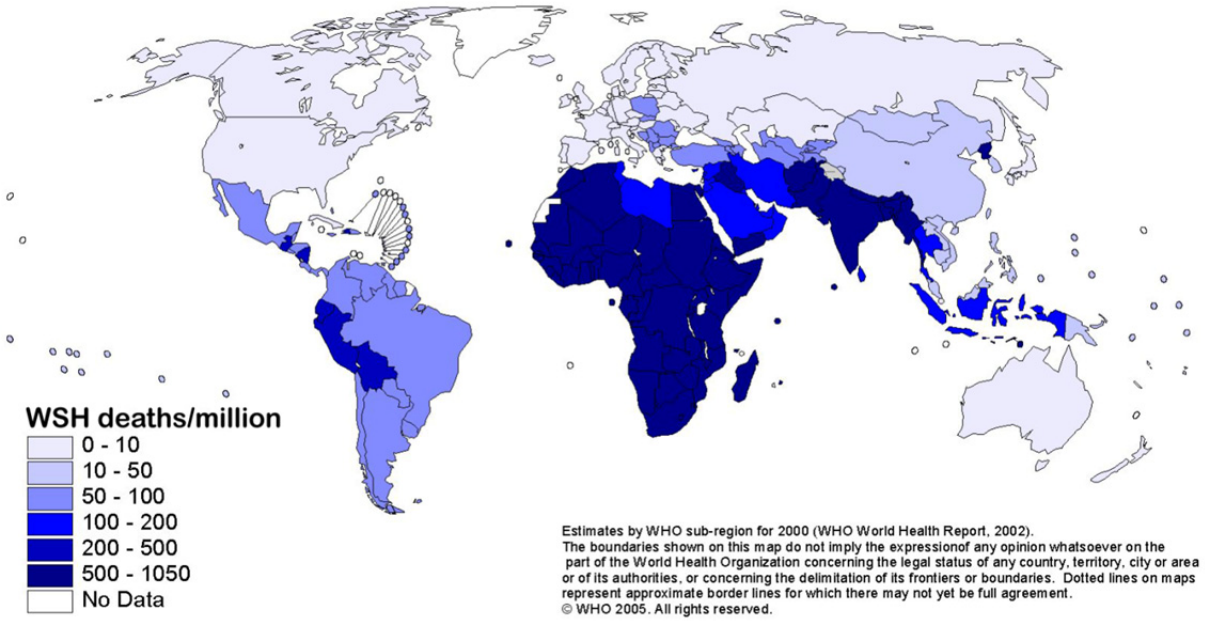


EXHIBIT A.5.3. GLOBAL DISTRIBUTION OF WATER, SANITATION, AND HYGIENE-RELATED DEATHS.

Source: WHO, 2012b.

WHAT ARE THE OPTIONS FOR PROTECTING WATER QUALITY?

Water quality considerations can start at the water source (e.g., lake, river, spring, or well) and go all the way through use. In developing countries, the concept of "source-to-tap" is often used to describe multiple barriers for the protection of water quality. These barriers can include:

- ***Source water protection.*** Efforts to reduce or eliminate contamination of the water source.
- ***Water treatment.*** Removal of any contaminants through water treatment processes. Water treatment can consist of multiple barriers such as filtration and disinfection.
- ***Protection of the distribution system water quality.*** Ensure that water does not get contaminated between the water treatment plant or distribution center and delivery to the consumer.

LIMITING FERTILIZER USE IN NICARAGUA AND GUATEMALA

A Nicaraguan program to improve agricultural practices, Programa Campesino a Campesino, reduced the use of chemical fertilizers by 90% and increased yields through rotating crops, using natural fertilizers, planting cover crops, and other methods (UNEP, 2010). In Guatemala, efforts being made to reduce nutrient runoff have resulted in reduced algal blooms in Lake Atitlán (UNEP, 2010). Strategies employed include the construction of sewage treatment plants in nearby communities and the adoption of organic farming practices on lands draining to the lake. The plan is expected to cost US $350 million (UNEP, 2010).

A wide range of contaminants can impact water quality and can include:

- ***Microbial and bacterial contaminants.*** These contaminants are often associated with waterborne illnesses that may cause diarrheal disease or several diseases of major public health concern. Pathogen contamination may include infectious bacteria (e.g., cholera, *E. coli*), protozoans (e.g., *Giardia*, *Cryptosporidium*), or viruses (e.g., hepatitis). Contamination is often related to human or animal wastes entering the water system, or inadequate treatment of wastewater.
- ***Organic, inorganic, or radiological contaminants.*** These contaminants can lead to long-term (chronic) health problems and occasionally acute health issues. There can be a wide range of sources, including agricultural runoff (e.g., fertilizers and pesticides), industrial discharges, and household wastewater. In some cases, these contaminants can be naturally occurring in surface or ground waters, as is commonly the case for arsenic and radionuclides (although these contaminants may also be introduced by human activities).
- ***Nutrients.*** This class of contaminants can lead to algal growth and low dissolved oxygen content (eutrophication). Algal growth can lead to objectionable taste and odors, and to the formation of algal toxins that pose a risk to human health. Low dissolved oxygen levels caused by algal growth can lead to fish kills and mobilization of some contaminants. Sources of nutrients in waters include agricultural runoff of fertilizers and animal wastes as well as human waste (e.g., inadequately treated wastewater).
- ***Physical aspects.*** Water color, turbidity, odor, and other physical properties may affect the ability to use that water for specific purposes. Erosion caused by land disturbances such as deforestation can lead to increased sediment build up and color changes. This can block sunlight, impacting photosynthesis and aquatic life, and making water disinfection and treatment difficult.
- ***Salts.*** Saline contamination can lead to water that is unpalatable or unhealthy. Salinization can be caused by sea level rise or saltwater intrusion due to over extraction of groundwaters. Some groundwaters may have high levels of naturally occurring salts, making them unsuitable for consumption.

The United Nations water program identified four strategies to improve water quality. These four strategies are prevention of pollution, treatment of polluted source water, safe use of wastewater, and restoration and protection of ecosystems (UN-Water, 2011). Exhibit A.5.4 highlights these approaches and provides some examples of each approach in different sectors and contexts. Each of these four strategies is explored in greater detail in their respective sections below.

EXHIBIT A.5.4. STRATEGIES TO IMPROVE WATER QUALITY.

Prevention of pollution (e.g., source water protection, wastewater treatment and management)	
Industry	Ensure adequate treatment of industrial wastewater. Reformulate products to produce less pollution and require less water during manufacturing.
Agriculture	Reduce pesticide, nutrient, and overall water usage by adopting crop rotation, cover cropping, conservation agriculture, improved irrigation management, and integrated pest management.
Household	Improve sanitation, stormwater management, and reduce wastewater production.
Treatment of polluted source water (e.g., rendering water quality suitable for potable use)	
Large settlements	Construct multiple-stage water supply (and wastewater) treatment plants.
Community	Install small-scale or package treatment that may support disinfection and filtration.
Household	Use point-of-use treatment (e.g., boiling, water filters, solar water disinfection, and chlorine treatment).
Safe use of wastewater (e.g., wastewater treatment and management, and water reuse)	
Industry	Use wastewater in applications that do not require high-quality water.
Agriculture	Practice ecological sanitation-separate livestock urine and fecal matter: urine can be applied to plants while fecal matter is composted.
Restoration and protection of ecosystems (e.g., land use management, source water protection)	
Watershed restoration	Restore rivers and wetlands to reduce flood risk by increasing the retention capacity of the landscape (e.g., use of green infrastructure and low impact development, as well as ecosystem services from important watershed features such as wetlands), which prevents pollution from entering waterways.
Source: Adapted from UN-Water, 2011.	

These four approaches are relevant both for extending access to high-quality water to underserved populations and for addressing climate impacts on water quality. In addition, implementing measures to improve water quality often can integrate more than one of these approaches. The United Nations Environment Programme (UNEP) and the WHO recommend that, when possible, pollution prevention should be emphasized over treatment and that pollution controls should be implemented at the lowest possible level (e.g., household-level actions are better than regional actions; UNEP/WHO, 1997).

Option A: Prevention of Pollution

It is often more cost-effective to reduce pollution at the source rather than to remove it from groundwater or surface water after contamination. Pollution prevention activities can address point sources or diffuse (i.e., non-point) sources. Some pollution sources, like household waste, can be considered either a point or non-point source.

For point sources (e.g., industrial facilities, mining, power production), pollution prevention starts with wastewater treatment for facility discharges. The type of treatment can be matched to the contaminants that may potentially be discharged. Pollution prevention may also include reformulating industrial products to create less pollution and require fewer resources (UNEP, 2010).

WETLANDS RESTORATION IN IRAQ

UNEP and the Ministry of Water Resources of Iraq initiated the Iraqi Mesopotamia Marshlands project in 2004 to address the destruction of the wetland ecosystem and its associated environmental consequences (World Water Assessment Programme, 2009). The project involved the reinundation of marshlands, construction of wetlands, development of water treatment facilities, installation of water distribution pipes, and installation of common drinking water distribution taps (World Water Assessment Programme, 2009).

Agricultural runoff is a major source of non-point source pollution. Runoff from agricultural and impervious urban land contributes significantly to nitrogen and phosphorus in surface waters, particularly after heavy precipitation, contributing to algal blooms (Tong and Chen, 2002). As the frequency and intensity of precipitation events are projected to increase in some regions, land use management strategies that reduce this runoff can improve surface water quality.

There are a number of well-established measures to reduce pollution from agricultural activities. Crop rotation, mulching, composting, cover cropping, terracing, conservation (e.g., low- or no-till) practices, shoreline buffer strips, and integrated pest management all can reduce nutrient and pesticide runoff and associated non-point source loadings to waterways (UNEP, 2010). Using drip irrigation can reduce both water use and runoff and any remaining runoff can be reclaimed and reused (UNEP, 2010). Developing and adopting less harmful pesticides and reducing fertilizer use can also improve water quality (Whitehead et al., 2009).

Reducing pollution at the household level includes both reducing total water use and treating wastewater at the household level before it is returned to the hydrological cycle. Household-level wastewater treatment will be addressed in the next section.

RETHINKING LEATHER PRODUCTION IN ZIMBABWE

One way to prevent pollution to water sources is to reduce pollution created by manufacturing processes. Improving manufacturing processes can reduce the risk of pollution to surface water and groundwater, reduce the burden on wastewater treatment facilities, and save money for firms and the public sector. The Cleaner Production Technology project, developed by Zimbabwe and the Danish International Aid Agency, redesigned the production process used at tanneries in Harare to reduce costs to treat wastewater from the company (UNEP, 2010). The adoption of this new process reduced pollution levels in wastewater by 50%, produced annual savings of US $13,500, and repaid the initial investment in three years (UNEP, 2010).

Option B: Treatment of Drinking Water and Wastewater

Water treatment happens at both ends of the human water use cycle. Providing safe drinking water often requires treatment prior to consumption. Treating wastewater before it is returned to the water use cycle can limit the pollution load in surface waters, which are often used downstream.

Drinking water treatment can be done at the municipal, community, or household level. The advantage of municipal-level water treatment is the cost efficiency and consistency gained by increasing the treatment scale. However, large-scale municipal water treatment presents challenges, including high capital and operating costs, potentially energy-intensive treatment technologies, a need for specialized skill sets, and coordination

and involvement of numerous administrative bodies. Developing countries may have insufficient access to the financial, human capital, and governance resources required for sustaining large-scale municipal water treatment facilities. In addition, relying on energy-intensive technologies may be cost- or resource-prohibitive. For these reasons, drinking water treatment at the community- and household-levels is often particularly attractive in developing countries.

There are a number of examples of drinking water treatment technologies being deployed in developing countries. Household-level options include chlorine disinfection, ceramic filters, reverse osmosis, flocculation, solar disinfection, and boiling (UNEP, 2010).

In addition to treating drinking water before consumption, wastewater should be treated before it is returned to the hydrologic system. Wastewater treatment often involves the physical separation of wastewater into solid and liquid components and chemical treatment to disinfect liquids (UNEP, 2010). Like drinking water, wastewater treatment can be done at the municipal, community, or household level. Many of the limitations of municipal drinking water treatment also characterize municipal wastewater treatment.

Community-level wastewater treatment technology is being developed to reduce the economic inefficiency of small-scale systems (UNEP, 2010). Membrane bioreactors, micro-filtration, reverse osmosis, electrodialysis, and other advanced technologies are making water treatment available at lower cost than previously available (UNEP, 2010). DEWATS, or decentralized wastewater treatment system, is being used in India, Southeast Asia, and Africa. It involves wet ecosanitation (i.e., settling tanks and filtration units are combined with wastewater lagoons and natural vegetative root filtration) and uses relatively little energy (UNEP, 2010). Biological solutions include constructed wetlands that use plant systems to break down contaminants (UNEP, 2010).

Household-level wastewater treatment can be accomplished through septic tanks or dry toilet systems. Dry toilet systems often involve ecosanitation principles in which solid waste is composted for use as fertilizer and sterile urine is applied directly to plants (UNEP, 2010).

Option C: Safe Use of Wastewater

In addition to treating wastewater and returning it to the hydrological cycle, wastewater can often be reused to reduce pressure on drinking water supplies and prevent pollution of surface waters. If effectively treated and used in appropriate ways, wastewater can be reused at the household level and in agricultural and industrial settings. The General Motors de Mexico Ramos Arizpe Complex instituted a wastewater treatment process that enables the facility to recover and reuse 70% of its industrial wastewater through physical, chemical, and biological means (World Water Assessment Programme, 2009). Exhibit A.5.5 illustrates a household-level wastewater reuse system that integrates rainwater capture and storage, the reuse of wastewater, and the use of biological treatment methods.

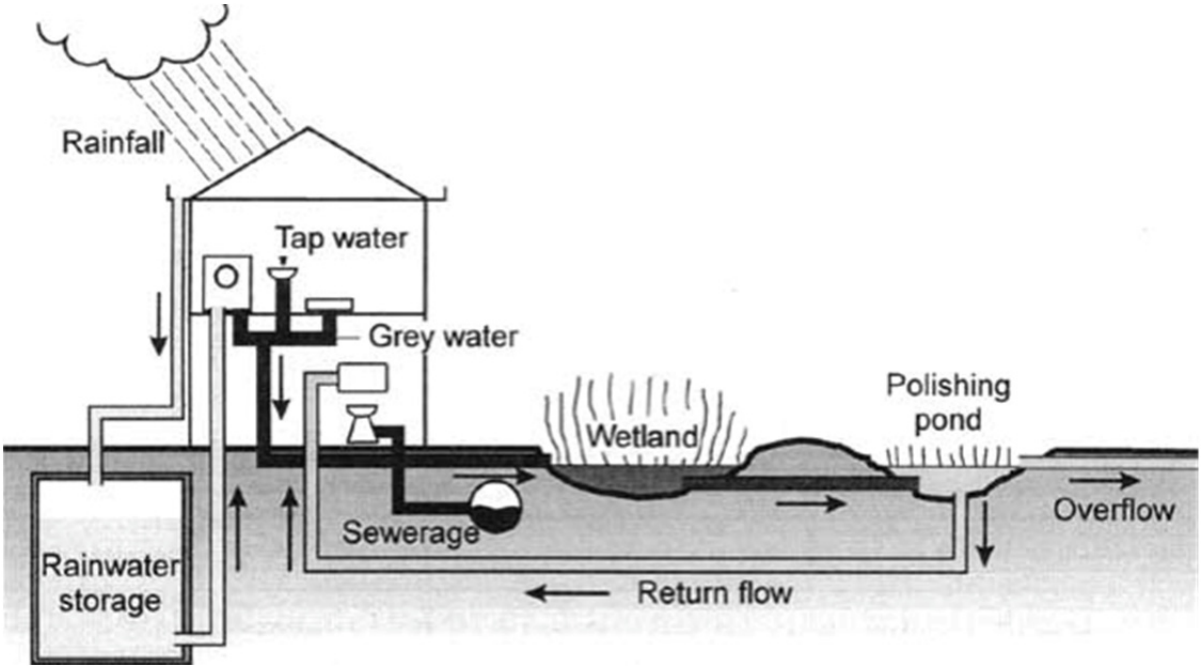


EXHIBIT A.5.5. HOUSEHOLD WASTEWATER REUSE SYSTEM.
Source: UNEP/WHO, 1997.

Option D: Restoration and Protection of Ecosystems

Ecological restoration involves using principles of natural ecological processes to improve water quality. For example, constructed wetlands can be used as large-scale filters to improve water quality. However, it must be noted that constructed wetlands rarely perform at the same level as healthy, natural wetlands (UNEP, 2010). Restoration of natural wetland and floodplain processes can also be used to address point- and non-point source pollution and effectively restore water quality at the basin scale (UNEP, 2010). The United Nations Educational, Scientific, and Cultural Organization and UNEP have undertaken a demonstration project in the Pilica River basin in Poland that aims to mitigate point and non-point source pollution through increasing retention of pollutants in the floodplain, and regulating water retention time to optimize the ecosystem's natural denitrification processes (UNEP, 2010).

Source water protection can protect drinking water supplies from contamination at a lower cost than water filtration infrastructure (see *Adaptation Action 8: Protect Inland Freshwater Ecosystems and Ecosystem Services* for a more detailed discussion or protecting freshwater ecosystems). But other land protection measures, such as preserving forests to avoid sedimentation of freshwater sources, are also important. Adaptation measures to restore polluted ecosystems include managing water levels in wetlands, lakes, and rivers, and designating vegetation corridors and buffer zones (Whitehead et al., 2009). Maintaining and restoring riparian wetlands, hedges, and forests can also reduce sediment and nutrient transport to waterways (Whitehead et al., 2009).

CERAMIC WATER FILTER USE WORLDWIDE

Potters for Peace has developed a ceramic filter that can be used to produce safe drinking water at the household level. The group now trains the local population to produce filters in Cambodia, Cuba, El Salvador, Ghana, Guatemala, Honduras, Indonesia, Kenya, Mexico, Sudan, and Yemen (World Water Assessment Programme, 2009). Water Health International is providing a community-scale water treatment technology that filters and disinfects up to 20 liters of drinking water per person per day to 600 communities in India for US $15 million (UNEP, 2010).

WHAT NEEDS TO BE CONSIDERED FOR IMPLEMENTATION?

Each potential adaptation option should be thoroughly analyzed in order to select the best course of action. Typical considerations for any given adaptation option are listed in the "Adaptation option considerations" text box. Given these considerations, a mix of adaptation options may be utilized to address specific climate risks to a community, region, or nation.

ADAPTATION OPTION CONSIDERATIONS

- Benefits/co-benefits
- Cost/financing
- Effectiveness
- Feasibility
- Flexibility
- Timeframe
- Robustness to climate stressors
- Unintended costs

Expanding access to high-quality water has clear economic and public health benefits. Climate impacts introduce additional considerations that should be taken into account in efforts to expand access to and protect water quality. Potential actions recommended by UNEP and the WHO emphasize implementing water quality solutions at the lowest administrative level possible. For example, transforming agricultural practices to reduce pesticide, herbicide, and fertilizer use; reduce water use; and reduce runoff can prevent pollution of surface waters. Reformulating industrial processes to use less water and produce less pollution can also reduce the contamination of surface waters. Capturing and reusing wastewater from agricultural, industrial, and domestic uses can also prevent pollution of surface waters. All of these measures are low to medium cost and may pay for themselves in water savings. Reducing the risk of groundwater salinization and saltwater intrusion to coastal aquifers by reducing extraction is another example of pollution prevention. Finally, protecting and restoring ecosystems can prevent pollution by promoting natural processes that neutralize pollutants.

Implementing Solutions at the Lowest Possible Administrative Level

Addressing water quality issues at the lowest possible administrative level minimizes the financial, human, capital, and political resources needed for implementation. The agricultural, industrial, and domestic pollution prevention measures described in Option A above can be implemented at the farm, firm, or household level. Community- or household-level drinking water treatment is another example of water quality improvement measures that can be implemented without municipal or regional coordination. Water conservation and reuse, which can help prevent contamination of surface waters and reduce pressure on groundwater resources, can also be implemented at the household or community level. In each of these cases, however, measures that can be implemented at low levels and small scales must eventually be adopted broadly in order to maximize their potential benefits.

Integrating Climate Adaptation and Development

Many of the strategies described above can effectively integrate the goals of expanding access to safe drinking water and sanitation in ways that are resilient to climate change impacts. Those measures that emphasize reducing runoff both limit pollution and prepare for changes in the frequency or intensity of precipitation. Efforts to protect and restore ecosystems can help reduce human-caused stress on those ecosystems,

improving their resilience to environmental stress caused by climate variability and change. Steps to reduce water consumption through conservation or wastewater reuse help prepare communities for future conditions in which available freshwater is less abundant.

Include Climate Impacts in Planning of New Facilities

Water quality managers may need to modify designs or strategies to account for climate impacts. For example, due to an increase in the intensity of storm events, siting water or wastewater treatment facilities outside the 100-year floodplain may not be satisfactory. Increased wastewater treatment capacity may also be needed to account for more intense storm events. Conversely, treatment requirements may need to be modified to account for lower flows that might occur under drought conditions.

Exhibit A.5.6 provides a summary of some of the major implementation considerations for adaptation options to protect water quality. For each option, the table identifies key feasibility challenges in implementation; the relative cost of implementation (to other options included in the table); the level of decision-making typically involved (e.g., national, regional, or local); and other considerations including benefits, effectiveness, flexibility, unintended costs, or timeframe.

EXHIBIT A.5.6. IMPLEMENTATION CONSIDERATIONS FOR WATER QUALITY PROTECTION ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Prevention of pollution – Agriculture	• Relatively easy to implement • Education and incentives may be needed to change practices	• Low to moderate based on the technique applied • May result in an overall cost savings through improved practices	• Decision can be made at individual farm or community level • Higher-level decisions can incentivize or provide technical/financial resources	• Projects may be started and completed quickly
Option A: Prevention of pollution – Industry	• May require significant design and engineering • May require modification to existing approaches • Requires an evaluation of alternative technologies	• May require significant capital and operations costs • Reformation of products may require an initial investment, but may have relatively quick repayment	• Can be accomplished facility by facility • Regulations can be used on a national or regional basis	• Requires planning and process redesign

EXHIBIT A.5.6. IMPLEMENTATION CONSIDERATIONS FOR WATER QUALITY PROTECTION ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option B: Treatment of wastewater	• Municipal- and community-based solutions will require significant design and engineering • Implementation at the household or small community levels will require less effort	• Municipal and community systems will require significant capital investment, and O&M and planning costs • Relatively low cost for household and small community systems	• Can be conducted at the household, community, or municipal level • Regulations can be used at a national, regional, or local level	• Household projects can be started and completed quickly • Community- and municipal-based systems will take significant time to design and construct
Option B: Treatment of drinking water	• Can be implemented at a household or community level	• Requires significant capital investment • Community level requires significant O&M • Planning costs necessary for siting and engineering of large facilities	• Decision can be made at the household or community level	• Community level will take significant time to design and construct • Household units can be installed rapidly
Option C: Safe use of wastewater	• Requires wastewater collection system, treatment system, and distribution system infrastructure • Requires design and engineering	• Requires significant capital investment • Requires significant O&M • Planning costs necessary for siting and engineering	• Decision typically made at the community/local government/regional government level	• Will take significant time to design and construct; time greatly reduced if wastewater collection and treatment infrastructure currently in place • Provides a significant new source of water for non-potable, indirect potable, or direct potable use • Not impacted by drought conditions

EXHIBIT A.5.6. IMPLEMENTATION CONSIDERATIONS FOR WATER QUALITY PROTECTION ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option D: Restoration and protection of ecosystems	• Protection requires governance and enforcement capacity • Restoration can be complicated and require specialized knowledge	• Land and ecosystem protection can be inexpensive, but may forego economic development opportunities • Restoration can be expensive	• Ecosystem protection and restoration typically require coordination across multiple levels of government	• Ecosystem protection can be implemented immediately • Restoration can take many years to generate benefits

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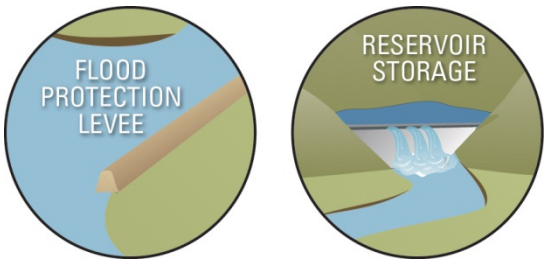
ADAPTATION ACTION 6 – STRUCTURAL APPROACHES TO FLOOD PROTECTION



Structural adaptation approaches can help protect vulnerable lands, people, infrastructure, and resources from destructive inundation caused by increased flooding and sea level rise. These approaches can include (1) structures and armoring that protect existing settlements by shielding them from inundation, (2) accommodating climate change by designing structures to withstand anticipated impacts, and (3) retreating to avoid destructive inundation. Major implementation issues to consider include selecting an appropriate design, costs, external demographic drivers, and development goals. It can be beneficial to implement structural options alongside non-structural adaptation measures (see *Adaptation Action 7: Non-structural Approaches to Flood Protection*). Note that *coastal* flooding is discussed in more detail as part of the coastal annex to the USAID climate-resilient development framework (USAID, 2014).

HOW CAN STRUCTURAL APPROACHES CONTRIBUTE TO CLIMATE RESILIENCE?

Structural approaches can enhance a community's climate resilience by shielding infrastructure from flooding events or inundation, by enabling infrastructure to withstand flooding or inundation, or by keeping infrastructure outside flood or inundation zones. Human populations are often highly concentrated in flood-prone areas and many lack protective infrastructure or disaster-response services. As populations grow in these areas, the level of exposure and vulnerability of these populations will increase unless protective measures are undertaken.

Climate stressors may impact the need for structural approaches. Exhibit A.6.1 summarizes some of the ways that structural approaches can contribute to climate resilience.

EXHIBIT A.6.1. HOW STRUCTURAL APPROACHES CAN IMPROVE RESILIENCE TO CLIMATE IMPACTS ON FLOODING.

Climate change impact	Benefits from structural approaches
Shorter, high-intensity storms	• Protecting and armoring riverbanks and shorelines can limit damage to infrastructure along floodplains and coasts during extreme events • "Managed retreat" by choosing not to rebuild in disaster-prone areas will limit future damage
Sea level rise	• Elevating or relocating structures can accommodate increased sea level and higher storm surges • Armoring of shorelines can protect existing infrastructure along vulnerable coastlines

WHAT ARE THE OPTIONS FOR STRUCTURAL APPROACHES TO PROTECT AGAINST FLOODING?

Structural approaches involve the construction of physical barriers or other structures to prevent damage and harm from destructive inundation. Structures can be built with the goal of protecting infrastructure and populations from flooding events or inundation and/or enabling infrastructure to withstand flooding or inundation. Relocating vulnerable structures is another option to prevent damage to infrastructure or population centers.

Structural approaches are distinct from non-structural approaches (which do not involve physical structures and defenses), but can be used in conjunction with these and other approaches. For example, non-structural activities such as improved warning systems can be combined with efforts to create elevated safe islands to increase the protection of populations and property during storm events. *Adaptation Action 7: Non-structural Approaches to Flood Protection* provides information on non-structural approaches, and *Adaptation Action 9: Manage Critical Interdependencies between Energy and Water* provides information on emergency backup energy supplies for water and wastewater facilities to enable treatment and distribution after flood events.

In some cases, structural protection measures may be the only practical option for avoiding damage from inundation (NOAA, 2010). For example, in Bahraich, a municipality in Uttar Pradesh, India, the district administration determined that it was necessary to reinforce and elevate hand pumps located in severely flooded areas to ensure access to safe drinking water during flood events (District Administration of Bahraich, 2010).

The three options described below include Option A: protecting and armoring land and structures with hard infrastructure such as dams, dikes, seawalls, and levees that protect areas exposed to inundation from damage; Option B: accepting and accommodating inundation by raising the height of structures above flood waters or using floating structures that are more resistant to inundation; and Option C: managing retreat by relocating settlements away from threatened areas.

Option A: Protect and Armor

Shoreline barrier and armoring approaches rely on hard infrastructure to reduce the risk of flooding, erosion, or inundation of land and structures. Barriers such as dams, dikes, and tide gates channelize river levels, hold back sea waters, or manage water flows. Armoring – by use of levees, coastal seawalls, and bulkheads – defends dry lands and fragile shores against flooding and strong waves and prevents land behind the structure from inundation or erosion. These structures usually constrain the river flow or fix the shoreline in its current place. Some flood prevention structures require pumping water out of low-lying lands or periodic opening and closing of barriers.

- ***Structural barriers.*** Communities can protect a large area of land (and the occupying settlements and infrastructure) from occasional high flows through construction and maintenance of structural barriers. Structural barriers such as levees and dikes or dams and locks manage water flow. They either permanently contain water within an existing waterway or are an engineered structure that can be temporarily deployed to constrain water to reduce the worst flooding. These types of barriers may require drainage and pumping systems to remove water trapped behind them during or after storms. In coastal areas, tide gates (i.e., barriers across small tidal bodies of water) or storm surge barriers (i.e., structures across larger bodies of water subject to surge) can be closed during storms or high

PROTECTING THE COASTAL ZONES IN TANZANIA

The coastal zone of Dar es Salaam, Tanzania, is prone to erosion and flooding, and will face sea level rise and inundation. A sea wall totaling 2.6 km exists to protect the city from the sea but is showing signs of severe degradation. The city is rehabilitating a portion of the sea wall, particularly around priority settlements and infrastructure, including government buildings, hospitals, and a training institute. The reconstruction and upgrade will also occur in areas of high risk of increased sea level and wave action, and is designed to withstand higher sea levels and stronger surges. The sea wall rehabilitation is expected to protect more than 450,000 people, 200,000 daily commuters, and over US $170 million of public and private investment and infrastructure (Adaptation Fund, 2012).

flows and then re-opened during low tides and normal flows. Tide gates can be used on a regular basis, following the daily or lunar tides or only for abnormal or storm-driven high tides.

- ***Armoring.*** Communities can also use engineered structures to armor river banks, shorelines, and beaches from erosion due to high flows and strong wave action. Armoring is often used along important transportation routes such as highways and railroads or on the water side of residential or industrial areas to fix the shoreline in its current place and prevent the loss of land. These structures include seawalls (i.e., vertical walls designed to withstand severe storms), bulkheads (i.e., vertical walls designed to prevent land from slumping toward the water), and retaining structures or other forms of coarse boulder armoring that reduce the energy intensity of strong flows and waves. Armoring approaches can also include fixed/dynamic revetments, fixed walls that slope toward the water to dissipate wave energy and dunes, or dynamic accumulations of sand and other materials as a temporary barrier against waves. In coastal areas, armoring can also include groins (i.e., hard structures extending out and perpendicular to the shore) and breakwaters (i.e., hard offshore structures parallel to the shore) to mitigate erosion due to waves. If built to a sufficient height, armoring can be used in combination with other strategies to protect existing settlements and other infrastructure from rising waters.

Option B: Accommodate

Accommodation allows communities to protect smaller areas or specific structures. Communities can design new, or retrofit existing, structures to accommodate changing climate conditions. When deployed in new construction, these approaches tend to have a lower initial cost than larger-scale barriers and armoring. Additionally, communities can set aside areas to capture or store flood waters and storm surges to protect adjacent or inland developed land.

- ***Elevate.*** Elevating buildings and infrastructure by constructing them or moving them onto higher foundations or pilings serves to raise the structures above predicted flood levels. Additionally, land can be elevated by adding sand, soil, or gravel. Small areas may be elevated to serve as protective islands where people, livestock, and other valuable property can relocate during flood events.
- ***Planned destruction.*** Structures and their components can be constructed with the anticipation that they may be destroyed by extreme flood events. Rather than reinforce structures or "engineer a solution," settlements may be assembled from low-cost materials using simple designs and methods that can be quickly rebuilt after a flood event. The planned destruction of parts or entire structures is also useful where the obstruction of water flow or drainage after a flood could have significant economic and/or environmental costs.
- ***Float.*** Structures can be designed to move with the water level. Flood-resilient structures (e.g., floating homes anchored to the shoreline), and flexible roads and water pipes may suffer less damage from inundation because they are able to rise and move with water levels. These approaches can better accommodate uncertain future flood levels.

ELEVATING HOMES IN BANGLADESH

The riverine areas of Bangladesh, known as Chars, are extremely vulnerable to frequent flooding and erosion and are home to some of the poorest and most vulnerable communities in the country (Islam and Mechler, 2007). The Chars Livelihoods Programme is working to reduce the vulnerability of up to 2.5 million dwellers by constructing earth platforms upon which inhabitants reconstruct their individual homes. The level of the raised land varies by community, but takes into account the maximum observed flood level (up to a 20-year flood) and sea level rise. The adaptation projects elevate other structures including hand-dug wells and latrines, and incorporate a non-structural approach of protecting the slopes of the elevated land with grass and trees.

- ***Reduce water flow rate.*** Communities can slow water flow to reduce downstream flooding or wave energy during coastal storms. Natural features (e.g., wide flood plains, expansive coastal marshes) historically served these functions in many areas, but may now be inhabited or degraded. Communities can create retention areas that capture, and then release water during heavy rainfall or storm surges or create large open plains behind levees to serve this purpose. Land that is not in use (e.g., coastal or forested lands) or lands routinely used for other purposes but able to withstand occasional flooding with little loss of function or damage (e.g., some agricultural lands) can also be utilized.

Option C: Managed Retreat

Moving people and resources away from areas vulnerable to flooding impacts is often referred to as managed retreat. This approach could entail limiting new development over time or abandoning a damaged area after an event.

- ***Ban or limit new development.*** Communities can ban or limit development in areas likely to be affected by inundation through land use policies such as density restriction; restricting additional development in flood-prone areas; restricting the size of built structures; modifying building codes to increase the size or height of new construction; or outright banning of any new development at a location. These approaches allow for a gradual shifting of new development away from threatened areas and are most cost-effective when applied to new construction.
- ***Establish triggers for demolition or abandonment.*** Communities may choose to delay relocation until there is a greater or more certain threat. Communities can establish specific indicators, such as the frequency of intense precipitation or a certain level of sea rise, which would trigger changes in development rules or require abandonment of threatened areas. Restrictions on new development and triggers for abandonment may be used in combination.
- ***Relocation.*** Communities may decide to abandon flood-damaged or flood-prone areas and relocate to safer locations. Relocation could be accomplished over the long-term through restrictions on new development or as a result of a trigger as discussed above. In many cases the potential costs of relocation can be significantly less than the costs of frequent rebuilding, particularly over the long-term. There are many cultural, political, and logistical barriers, however, that may make relocation a less-favorable option.

WHAT NEEDS TO BE CONSIDERED FOR IMPLEMENTATION?

Each potential adaptation option should be thoroughly analyzed in order to select the best course of action. Typical considerations for any given adaptation option are listed in the "Adaptation option considerations" text box. Given these considerations, a mix of adaptation options may be utilized to address specific climate risks to a community, region, or nation.

ADAPTATION OPTION CONSIDERATIONS

- Benefits/co-benefits
- Cost/financing
- Effectiveness
- Feasibility
- Flexibility
- Timeframe
- Robustness to climate stressors
- Unintended costs

As this is the case, non-structural (see *Adaptation Action 7: Non-structural Approaches to Flood Protection*) and structural options may be paired. Structural approaches are most appropriate for larger magnitude extreme events or protecting a specific area, but the relatively high costs and long timeframe associated with construction can be prohibitive. In addition, some structural approaches may involve undesirable long-term changes to shorelines or other natural features that have negative effects on ecosystems and ecosystem services. Structural approaches can also have unintended consequences to human systems, e.g., encouraging settlement in vulnerable areas. Therefore it is valuable to review key considerations in implementing structural approaches:

- ***Cost and financing.*** Structural approaches are usually expensive, especially in heavily developed areas. Financial assistance may be necessary, but must be carefully managed to minimize incentives to over-build structures (which later could result in loss of critical habitat, loss of access to water, and other negative impacts).
- ***Design considerations.*** Design of structural approaches requires engineering decisions regarding the height and extent of the structural changes, which will require technical expertise. Good information is also necessary to inform designs. Design decisions that employ generalized technical information or historical climate records rather than local knowledge and future projections can result in poor design, unnecessary costs, and/or insufficient protection from coastal and inland flooding hazards.
- ***Uncertainty and flexibility.*** There is significant uncertainty surrounding the future rate and intensity of climate-related flooding. Flexibility can be built into designs to allow them to be modified as the need arises. For example, structural measures, such as seawalls or dikes, can be designed to enable low-cost expansion in the future. Some approaches inherently have more flexibility than others. Barrier approaches that block flood waters will be ineffective if they are engineered below actual impact thresholds; in contrast, managed retreat options may be adjusted as flood impacts and sea levels become more certain. Local monitoring of inundation can help inform designs.
- ***Timing.*** Instead of replacing or fortifying a structure that has many years of useful life left, a decision-maker could wait until the structure or facility needs replacement (or at least significant repair) to relocate or armor. If a structure is in the planning stages, it may make sense to site it in a location that is not vulnerable to climate variability and change (if possible).
- ***Risky development due to perceived reduction in risk.*** Structural approaches can create a false perception of safety. Once structures have demonstrated an ability to withstand minor floods, additional development may be introduced close to the structure (referred to as the "development paradox"). If a future flood exceeds design criteria for that additional development, even more people or property may be at risk (Burby, 2006).
- ***Social equity.*** Poorer populations tend to live in more vulnerable areas and structural approaches may exacerbate inequities. For example, barrier structures may increase erosion and flooding downstream, where poor communities may reside. Conversely, managed retreat options may adversely impact populations who are less able to move.
- ***Ecological consequences.*** Structural options can negatively impact riparian and coastal ecosystems and the services they provide. For example, hard structures designed to protect shorelines from storm surge could block landward migration of habitats and beaches as sea levels rise. Preventing inland migration could adversely impact or lead to elimination of ecosystems. If armoring is used on the landward side of coastal wetlands, those wetlands may be lost as sea level rises (since the wetlands will not be able to migrate inland past the barriers). Structures intended to prevent erosion can have downstream consequences to the extent that they disrupt natural water and sediment flows.

Exhibit A.6.2 provides a summary of some of the major implementation considerations for structural adaptation options. For each option, the table identifies key feasibility challenges in implementation; the relative cost of implementation (to other options included in the table); the level of decision-making typically involved (e.g., national, regional, or local); and other considerations including benefits, effectiveness, flexibility, unintended costs, or timeframe.

EXHIBIT A.6.2. IMPLEMENTATION CONSIDERATIONS FOR STRUCTURAL ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Protect and armor				
Structural barriers: Tide gates and storm surge barriers	• Complex design and construction • Potential navigation restrictions (tide gates) • Potential adverse environmental, visual, or social impacts	Very high initial costs as well as O&M costs	National and/or multi-national	Long horizon to include planning, permitting, and construction
Structural barriers: Dams/dikes/artificial levees	• Moderately complex designs, earthen or concrete • Government permitting and property issues often problematic • Uncertainties of flood height • Difficult to pretest, resulting in possible failure due to design or lack of maintenance • Loss of habitat seaward of structure	Moderate (depending on costs of land acquisition), with moderate ongoing maintenance costs	Local and/or regional	Moderate depending on permitting and land acquisition
Armoring: seawalls, bulkheads, retaining structures, fixed revetments	• Standardized design and engineering • Limited protection from flood • Likely to fail in severe events • Can cause loss of seaward habitat • Potential adverse environmental, visual, or social impacts	Low to moderate, depending on size and materials	Local	Moderate, depending on permitting and land acquisition
Armoring: Dunes	• Standardized design and engineering, assuming space available • Little citizen opposition • Subject to wave erosion and catastrophic loss in storms • Short lifespan	Minimal	Local	Inexpensive to install but short life-span
Armoring: Groins and breakwaters	• Standardized design and engineering • Possible permitting issues • Limited flood protection • Groins can have controversial effects on adjacent lands; breakwaters can create navigation hazards	Minimal to moderate, depending on size	Local	Minimal to moderate, depending on permitting

EXHIBIT A.6.2. IMPLEMENTATION CONSIDERATIONS FOR STRUCTURAL ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option B: Accommodate				
Elevate: Create elevated safe islands	• More feasible than elevating entire areas • Most effective for rural areas • Assumes losses to resources that cannot move to island • Potential adverse environmental, visual, or social impacts	Moderate	Local	Minimal to moderate, depending on permitting
Elevate: Elevate structures	• Feasible for new or smaller structures • Large structure will likely require demolition and reconstruction	Minimal to moderate	Local	Moderate
Planned destruction	• Standardized or even simpler engineering • Requires rebuilding after destruction/inundation	Low cost (may be able to use lower-cost materials and simpler designs)	Local	Minimal to install but short life-span
Float: Design floating buildings and infrastructure	• Evolving technology with some successful applications • Most effective on small scale (e.g., residences)	Minimal (for individual residences) to moderate (for infrastructure, communities)	Local	Minimal to moderate, depending on complexity
Create retention areas for heavy precipitation or storm surge	• Standardized design and engineering depending on size • Requires significant area • Uncertainties of flood size • Potential adverse environmental, visual, or social impacts	Moderate	Local	Minimal to moderate (depending on permitting, land acquisition issues)
Option C: Managed retreat				
Ban or limit new development	• Effective for new construction • Difficult to enforce	Minimal, except for lost future value	Local	Moderate time to implement
Establish triggers for demolition or abandonment	• Gradually reduces resources at risk of catastrophic harm • Issues with taking property rights • Difficult to enforce	Moderate to high, depending on resource at risk	Local	Moderate time to implement
Relocate structures	• Highly variable depending on density, frequency of flooding, and value of existing structures • Total loss of existing resources	Moderate to very expensive, if existing structure requires compensation or reconstruction	Local to national (depending on scale)	Moderate to significant, if large populations or properties are involved

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ADAPTATION ACTION 7 – NON-STRUCTURAL APPROACHES TO FLOOD PROTECTION

Non-structural approaches to flood and inundation protection include strategies to promote the ability of natural systems to moderate flood waters and help people prepare, avoid, and recover from flood events. This adaptation action focuses on non-structural approaches that fall into three broad categories: (1) preservation, creation, or enhancement of natural buffering systems; (2) land-use planning and policies; and (3) disaster preparation, response, and recovery. Non-structural options can also be implemented alongside structural adaptation measures (see *Adaptation Action 6: Structural Approaches to Flood Protection*). Non-structural options can offer flexibility over time as well as environmental and developmental co-benefits, making them an important component of a comprehensive adaptation strategy. Note that *coastal* flooding is discussed in more detail as part of the coastal annex to the USAID climate-resilient development framework (USAID, 2014).

HOW DO NON-STRUCTURAL APPROACHES CONTRIBUTE TO CLIMATE-RESILIENT FLOOD PROTECTION?

Non-structural approaches include actions to restore the natural hydrologic buffering capacity of river systems, and actions to reduce flood risk through administrative or emergency response planning. The non-structural approaches described here can help reduce flood risk and build capacity to respond to and recover from flood events. Actions that help restore the natural hydrologic function of river and coastal systems can improve the capacity of the natural environment to buffer downstream reaches from flooding. This improved natural buffering capacity will improve resilience to a climate that might be characterized by more frequent or more extreme high-precipitation events. Restricting development in flood-prone areas, updating building codes, improving advance warning systems, and establishing evacuation routes and plans can also reduce risk by moving people, property, and other valuable resources out of harm's way. Non-structural approaches can be more flexible than structural approaches (*Adaptation Action 6: Structural Approaches to Flood Protection*), since they leave open the option to change course later. For example, restricting development in a vulnerable area in the near-term does not preclude later opening that area for development if future circumstances suggest it would be safe.

Even if these adaptation options are implemented, future flooding will still occur in many low-lying locations along rivers and coasts. Nearly all of these measures can be integrated into broader land development, water management, agricultural strategies, or disaster risk plans that promote resilience of lands and populations. Finally, insurance offers a way to reduce the recovery time and costs that communities and businesses face after an event.

Exhibit A.7.1 provides some examples of how non-structural approaches can aid in climate-resilient flood protection.

EXHIBIT A.7.1. HOW NON-STRUCTURAL APPROACHES CAN AID IN CLIMATE-RESILIENT FLOOD PROTECTION.

Climate change impact	Benefits from non-structural approaches
Shorter, high-intensity storms	• Preserving, enhancing, or protecting natural buffer systems such as wetlands, forests, and dunes will improve natural resilience to flooding and storm surge • Land-use planning and policies that limit development in disaster-prone areas can reduce exposure to inundation • "Green infrastructure" can minimize runoff and decrease urban flooding during extreme precipitation events • Disaster preparedness can limit human losses when extreme events occur
Sea level rise	• Protecting or restoring dune ecosystems can improve coastal resilience to sea level rise and storm surge • Restricting coastal development will keep infrastructure out of harm's way

WHAT ARE THE OPTIONS FOR NON-STRUCTURAL APPROACHES TO FLOOD PROTECTION?

As described above, non-structural adaptation approaches include actions to restore flood mitigation services provided by natural systems (i.e., to reduce the magnitude or frequency of damaging inundation), and actions to minimize damage and/or reduce recovery time when floods occur. The non-structural adaptation options described below are grouped into three broad categories: Option A: preservation, creation, or enhancement of natural buffering systems; Option B: land-use planning and policies; and Option C: disaster preparation, response, and recovery.

Option A: Preservation, Creation, or Enhancement of Natural Buffering Systems

Natural buffering systems can help prevent or delay inundation. Options to help restore the natural hydrologic cycle and minimize the impact of precipitation events include:

- ***Enhance natural buffers through ecosystem protection and restoration.*** Features of the natural environment can be used to manage or control flows of water. Marshes, forests, and wetlands can act as a buffering system that reduces the impact of river flooding. These natural areas can retain water onsite and slowly release the water into the surrounding areas, effectively slowing the rate of runoff through natural processes such as soil infiltration. Similarly, mangroves and estuaries can minimize the severity of coastal flooding. Beach dunes can act as a barrier to storm surges and waves that might otherwise damage upland communities or crops. The ability of these systems to provide a flood buffer can be preserved or enhanced through planting additional vegetation, or by preventing their destruction through development. Beaches and dunes can also be stabilized by replacing sand on an eroding shoreline.
- ***Minimize impermeable surfaces through low-impact development.*** Reducing or preventing the creation of impermeable (i.e., non-porous) surfaces can help reduce runoff and slow water flows. During a typical rainstorm, stormwater runs off all landscapes. The more impermeable surfaces that exist, the higher the volume and rate of runoff. Low-impact development design practices (e.g., installing permeable pavement and other elements of "green infrastructure") seek to minimize the disturbance caused by development and maintain the natural hydrologic function of a landscape. While these practices can be applied to any development at any time, they are especially beneficial in urbanized areas and optimally applied at the outset of development.

DISASTER PREPARATION AND WARNING IN MOZAMBIQUE

Catastrophic flooding in Mozambique in 2000 killed 700 people, destroyed the homes of over 500,000 people, and affected over one-quarter of the country's population (through damage to crops, schools, water management systems, and the transportation infrastructure). The government developed a warning system to disseminate information in advance (based on a system of color-coded "flags" that relate to levels of risk) about heavy rainfall, rising river levels, and threats from tropical storms. In 2007, heavy rains followed by tropical storm Favio led to large-scale flooding in Mozambique. Although the impacts were significant, the loss of life (29 deaths) and level of damage (approximately 140,000 people displaced and 285,000 people affected) were less severe than in 2000. The warning system and associated training, as well as other measures for disbursing food and water following the disaster, proved to be useful tools for reducing flood risk (Murray et al., 2012 and references therein provide details on this example).

Option B: Land-use Planning and Policies

- ***Restrict development in flood-prone areas.*** In countries where land-use policies are enforceable, development restrictions in flood-prone areas can be an effective approach to shift the growth of communities and infrastructure to less vulnerable areas. Development restrictions can also be used to protect natural systems that lower flood risk, such as wetlands along river or coastal shores. Setbacks may require construction to be sited a minimum distance from a river or shoreline. Distances can be established with the consideration of anticipated future flood risk and sea level rise.
- ***Encourage or require designs that will be flood-resilient.*** Flood risks, based on historical information and climate variability and change projections, can be factored into design standards or building codes for flood-prone or low-lying coastal areas. These standards and codes can encourage or require flood-resilient design. For example, municipalities can incentivize building elevated structures that can withstand temporary inundation.

PREVENTING FLOODING IN HONDURAS AND INDIA

La Ceiba, Honduras, is subject to frequent flooding and storm surges. USAID has been working with La Ceiba to develop the area as a tourist destination and minimize the occurrence of flooding. A vulnerability screening and analysis revealed that preventing deforestation in the watershed would reduce the impact of flooding, while providing the opportunity to increase tourism (USAID, 2008).

Pune, India is located at the confluence of the Mutha, Mula, and Pavana rivers. The city has been affected by several significant floods over the past six decades and projections show an increased expectation for flooding in the region. The city assessed rainfall intensity and areas where construction has altered the natural drainage system. They developed a plan with both structural approaches (e.g., widened streams and extended bridges) and non-structural approaches (e.g., natural soil infiltration, watershed conservation, afforestation, building small earthen dams, and installing flood monitoring and warning systems) to minimize erosion and the impact of flooding in the city (ISDR, 2009).

Option C: Disaster Preparation, Response, and Recovery

Disaster preparation, response, and recovery strategies can minimize loss of life and damage to property and livelihoods resulting from storm and flood events. Some examples include:

- ***Design, implement, and/or strengthen advance-warning systems.*** Flood and storm warning systems can alert communities that they should retreat to safe places (and secure property) in advance of a coming storm or flood event. Investments in warning systems can involve improving the equipment and

technology used to monitor weather and climate; training staff to better utilize weather and climate information; expanding cooperation or coordination with organizations that provide weather and climate services (such as the World Meteorological Organization); and developing, testing, and employing communication strategies for disseminating information about imminent weather or climate threats.

- ***Improve storm preparedness and disaster response.*** Current flood and storm preparedness practices should be assessed, and then opportunities to improve them can be identified and implemented. Actions to improve preparedness can include, for example, designation of evacuation routes and emergency gathering areas (which should be well-publicized in advance of an event); plans for maintaining communication systems and providing medical services at evacuation and emergency gathering areas; and training individuals that can assist in communication, transportation, and provision of health services during an event.
- ***Facilitate swift post-disaster recovery.*** Prior planning and strong institutions can facilitate restoration of critical services (e.g., communication, transportation, potable water, health) quickly after a disaster. Disaster insurance can also help individuals and businesses recover financial and property losses resulting from flood or storm events. Financial institutions can offer both disaster insurance and funds to cover individuals' basic needs (e.g., food, water, shelter) immediately after a disaster, relieving some of the stress on disaster aid programs.

MICROFINANCE AND INSURANCE IN HAITI

Fonkoze, Haiti's largest microfinance institution, has developed insurance coverage for small business owners to protect themselves against damage from hurricanes, earthquakes, floods, and wind events. This insurance is mandatory for entrepreneurs that receive loans from Fonkoze. Following a disaster, the insurance helps business owners cancel their current loan; provides indemnity payouts for food, water, and temporary shelter; and assists in getting a new loan. In June 2011, heavy rains led to flooding and mudslides in Haiti. The insurance offered through Fonkoze was successful in disbursing funds to borrowers (approximately US $125/borrower) who had lost their homes or businesses (ILO, 2012).

WHAT NEEDS TO BE CONSIDERED FOR IMPLEMENTATION?

Each potential adaptation option should be thoroughly analyzed in order to select the best course of action. Typical considerations for any given adaptation option are listed in the "Adaptation option considerations" text box. Given these considerations, a mix of adaptation options may be utilized to address specific climate risks to a community, region, or nation.

ADAPTATION OPTION CONSIDERATIONS

- Benefits/co-benefits
- Cost/financing
- Effectiveness
- Feasibility
- Flexibility
- Timeframe
- Robustness to climate stressors
- Unintended costs

A combination of non-structural and structural approaches will most often afford communities the best protection from flooding. Non-structural approaches may be able to effectively prevent damage incurred by smaller, higher-frequency events and lessen the severity of flood damage from large-scale flood events (e.g., storm surge damage from a tropical storm is unlikely to be stemmed entirely by beach nourishment and wetland enhancements). Structural approaches (described in *Adaptation Action 6: Structural Approaches to Flood Protection*) may be more appropriate for larger-magnitude extreme events or protecting a specific area, but the relatively high costs and long timeframe associated with construction can be prohibitive. In addition, some structural approaches may involve undesirable long-term changes to shorelines or other natural features that have negative effects on ecosystems and ecosystem services. Structural approaches can also have unintended consequences to human

systems, e.g., encouraging settlement in vulnerable areas. Combining disaster preparation, response, and recovery approaches with structural and other non-structural approaches will likely result in the most effective protection from flood and storm damage.

Important implementation considerations for non-structural approaches include:

- ***Timeframe.*** There may be regulatory delays or a lag-time for implementation that should be considered at the planning phase. For example, changes in building codes may be quickly implemented but the impact will only be realized once new buildings have been constructed. There may also be circumstances that make implementation more feasible at certain times (e.g., there may be heightened interest in flood protection immediately after a flood event).
- ***Costs and benefits.*** The cost and time needed to implement non-structural approaches can be significantly less than some structural approaches. Furthermore, some non-structural approaches may help "buy time" to further consider employing structural approaches. Other non-structural approaches can help make structures or land "safe to fail," e.g., by designing landscapes to mitigate flooding. Additionally, co-benefits (such as the increased biodiversity that could result from protecting wetlands) should be considered in any calculation of costs and benefits.
- ***Uncertainties in the magnitude of flooding.*** It is difficult to quantitatively estimate the magnitude of future flood risk due to uncertainties in projecting future rates of sea level rise and local subsidence, as well as changes in precipitation and storm events. Since non-structural approaches are generally more flexible and less permanent than structural approaches, they may be preferred in the face of significant uncertainty.
- ***Governance and property rights.*** It may be difficult to enforce policies that are designed to restrict development, particularly in regions where the institutions that design and enforce land-use policies are weak or considered illegitimate. Policies restricting development may also be in conflict with the property rights of land owners or land developers. Local or regional governmental institutions (e.g., courts) may need to adjudicate trade-offs between a collective interest in flood protection and individual interests in land use.

Co-benefits

Non-structural approaches can provide a range of environmental co-benefits. For example, conserving natural systems, such as forests and wetlands, can improve water quality, regulate the availability of water throughout dry seasons, and provide many valuable ecological services such as critical habitat for species. Conservation of wetland buffers and forests helps reduce soil erosion in agricultural areas. The development of early warning systems or strengthening evacuation planning can lead to improvements in communication and transportation networks, which can, in turn, contribute to an area's economic development.

Exhibit A.7.2 provides a summary of some of the major implementation considerations for non-structural adaptation options. For each option, the table identifies key feasibility challenges in implementation; the relative cost of implementation (to other options included in the table); the level of decision-making typically involved (e.g., national, regional, or local); and other considerations including benefits, effectiveness, flexibility, unintended costs, or timeframe.

EXHIBIT A.7.2. IMPLEMENTATION CONSIDERATIONS FOR NON-STRUCTURAL ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Preservation, creation, or enhancement of natural buffering systems				
Enhance natural buffers through ecosystem protection	• Moderate technical knowledge required • Depends on availability of land and resources • May face resistance from community members and other development interests	• Medium to high implementation costs, depending on land ownership and value	• Local, regional, or national	• Long-term benefit with many co-benefits • Can take many years
Minimize impermeable surfaces through low-impact development	• Low to moderate, technical knowledge required • May provide local employment opportunities for green space maintenance	• Low cost, varies by technique and scale	• Household, municipal, or regional • Techniques are often scalable, from local up to regional	• Relatively fast to implement • Prevents maladaptive development • Often provides important co-benefits
Option B: Land-use planning and policies				
Restrict development in flood-prone areas	• Moderate level of technical knowledge required to determine adequate setbacks • Easy to scale or replicate, depending on land availability • Public and land owners may not support policy • Existing land rights and enforcement challenges could limit success • Potential for limited availability of land not prone to inundation	• Low direct cost to government • Lost land for development represents a cost	• Local, regional, or national	• Implementation time depends on governance and political institutions • Benefits accrued over long timescales (years to decades) • Limits maladaptive development • Potential for ecological and other co-benefits

EXHIBIT A.7.2. IMPLEMENTATION CONSIDERATIONS FOR NON-STRUCTURAL ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Encourage or require flood-resilient designs	• Moderate technical knowledge required • Depends on availability of localized information • Depends on government ability to influence design and development, and enforcement	• Direct costs of drafting and passing new policies are typically low • Implementation costs dependent on the approach and effectiveness of enforcement mechanisms • Potential transactional costs in implementing policies (e.g., gaining political buy-in, disseminating information to developers)	• Local or national government	• Implementation time depends on governance and political institutions • Benefits accrued over long timescales (years to decades) • Limits maladaptive development
Option C: Disaster preparation, response, and recovery				
Design, implement, and/or strengthen advance-warning systems	• Low level of technical knowledge required • Disseminating information should go through established communication channels, which may be weak	• Training and technology can be expensive; coordination/ collaboration with existing services can be less expensive • Very cost-effective	• Local, regional, and national	• Fast to implement • Immediate, short-term, and long-term benefits
Improve storm preparedness and disaster response	• Low level of technical knowledge required • Likely requires many institutional partners to collaborate	• Low cost (e.g., $25,000 to $100,000 per training program)	• Local, regional, and national	• Fast to implement • Immediate, short-term, and long-term effects
Provide or encourage disaster insurance (facilitate swift post-disaster recovery)	• May need private or financial sector support to provide insurance	• Cost for insurance based on assets insured and level of risk • Premiums may pose cost burden on small enterprises	• Regional and national • Insurance decisions could be made by private companies under government regulation	• Relatively fast to implement • Insurance requires ongoing collection of premiums • Immediate, short-term, and long-term effects

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ADAPTATION ACTION 8 – PROTECT INLAND FRESHWATER ECOSYSTEMS AND ECOSYSTEM SERVICES

Inland freshwater ecosystems, including rivers, lakes, and wetlands, provide many important ecosystem services. Water supply-related ecosystem services include flow regulation and groundwater storage. Water quality-related ecosystem services include control of erosion and processing of wastes, pollutants, and contaminants. Agriculture, fisheries, tourism, and other sources of livelihoods are also dependent on freshwater. This adaptation action focuses on protecting inland freshwater ecosystems and the services they provide through adaptation strategies that promote best management practices to protect/restore key ecological resources, enhance governance mechanisms, and build institutional capacity.

HOW DOES INLAND FRESHWATER ECOSYSTEM PROTECTION CONTRIBUTE TO CLIMATE-RESILIENT WATER MANAGEMENT?

Healthy freshwater ecosystems serve important roles for water resources, including mitigating flood risk (see *Adaptation Action 7: Non-structural Approaches to Flood Protection*) and preserving water quality (see *Adaptation Action 5: Protect Water Quality*). Watersheds that lack vegetation are subject to flooding, erosion, and polluted runoff that is carried to downstream water bodies. Restoring watershed vegetation helps regulate flows by enhancing infiltration of water into the soil (thereby controlling excess runoff), and helps protect water quality by trapping sediments and pollutants. Preserving floodplains helps control the movements of water, sediments, and nutrients between river channels and the surrounding landscape, which is essential during times of heavy precipitation or rapid snowmelt. Strengthening governance mechanisms and enforcing them (see *Adaptation Action 10: Strengthen Water Governance*), as well as efforts to build institutional capacity to implement best management practices, will help protect inland freshwater ecosystems and increase their resilience to climate impacts.

Exhibit A.8.1 provides examples of how protecting freshwater ecosystems can contribute to climate-resilient water management.

EXHIBIT A.8.1. HOW PROTECTING INLAND FRESHWATER ECOSYSTEMS CAN CONTRIBUTE TO CLIMATE-RESILIENT WATER MANAGEMENT.

Climate change impact	Benefits from protecting inland freshwater ecosystems
Higher temperatures	• Healthy freshwater ecosystems such as forests help to moderate air and water temperatures, which benefits water quality by maintaining dissolved oxygen and limiting algal blooms
Reduced precipitation	• Healthy freshwater ecosystems increase infiltration of precipitation to the ground, helping to buffer hydrologic systems during low-flow periods • Wetlands help to sustain baseflow to streams, which can help maintain streamflow during dry periods
Shorter, high-intensity storms	• Healthy forests act as natural buffers to increase infiltration, reduce erosion, and reduce peak flows during high-intensity events • Wetlands and forests help filter sediment and associated contaminants during intense precipitation events, improving water quality
Sea level rise	• Enhanced infiltration of freshwater promoted by healthy ecosystems replenishes groundwater and can reduce the severity of saltwater intrusion near coasts

ASSESSING FRESHWATER RESOURCES IN TANZANIA

Climate change is expected to reduce water availability in the Pangani Basin, where water scarcity has already led to severe water conflicts between different users (including farmers, hydropower plants, fishermen, and residents). Tanzania's National Water Policy (Ministry of Water and Livestock Development, 2002) requires that water for the maintenance of aquatic ecosystems is ranked as the second-highest priority in allocation (after water for basic human needs). The Government of Tanzania is conducting a pilot Environmental Flow Assessment in the Pangani Basin to evaluate the ecological, social, and economic impacts of different flow scenarios. By 2010, the project had completed assessments of 15 flow scenarios, which took into account possible changes in both water supply (due to climate change and catchment management) and water demand (due to population growth, efficiency, and economic development). The results will serve as a basis for water allocation decisions (Hirji and Davis, 2009b; PBWO/IUCN, 2009).

WHAT ARE THE OPTIONS FOR PROTECTING INLAND FRESHWATER ECOSYSTEMS?

Freshwater ecosystems and the services they provide are essential for the provision of a clean, renewable supply of freshwater for human uses (MA, 2005). As described in *Adaptation Action 7: Non-structural Approaches to Flood Protection*, they also provide effective protection against droughts, floods, and other water-related climate impacts (Le Quesne et al., 2010).

Freshwater ecosystems regulate flows by maintaining base flows through soil drainage and groundwater discharge, absorbing overbank flows in floodplains, routing runoff to river channels, and recharging groundwater aquifers. Freshwater ecosystems protect water quality by controlling erosion, recycling excess nutrients, processing wastes, and absorbing pollutants and contaminants. These ecosystems and their services also support healthy fisheries and agriculture, contributing to food security, tourism, and livelihoods (MA, 2005).

Many of the adaptation options to increase climate resiliency of inland freshwater ecosystems can be categorized into (1) promoting best management practices to protect/restore key ecological resources, (2) enhancing governance mechanisms (policies and regulations), and (3) building institutional capacity (Le Quesne et al., 2010). Short descriptions of these categories and examples of specific activities are provided below.

Option A: Best Management Practices

Continuing or expanding efforts to protect freshwater ecosystems may be one of the most effective options to increase resilience to climate stressors. Best management practices can help to reduce non-climate stressors (e.g., overfishing, water pollution, surface water extraction, damming of rivers, modification and drainage of freshwater habitats and wetlands, non-native species invasions) and restore degraded ecological resources (e.g., WWF, 2008; TNC, 2009). Some specific options include:

Land use management decisions and related best practices can help to protect watersheds and provide source water protection. For example, efforts to reduce runoff of excess sediments and nutrients from logging, crop production, construction, and livestock grazing all help reduce pollution of freshwaters. Acquiring or restoring land next to lakes and rivers helps buffer water bodies from development pressures and allows for floodplain expansion as well as habitat protection.

Reducing sewage and other wastewater effluent inputs to water bodies helps improve water quality and support healthy fisheries (see *Adaptation Action 5: Protect Water Quality* for more details on wastewater and water quality issues).

Restoration of forests and soil conservation practices help protect downstream freshwater ecosystems from flood flows, excess sediments, pollutants, and nutrients in runoff.

Reconnecting floodplains to rivers (e.g., by re-grading river banks) helps regulate flows, store water, and control flooding. *Adaptation Action 7: Non-structural Approaches to Flood Protection* also discusses restoration of natural flood protection through ecosystem protection and restoration, and land use planning and policies.

Wetland reclamation enhances natural water purification, provides water storage, and increases groundwater infiltration by wetlands.

Option B: Watershed Management Policies and Regulations

Weak governance can lead to over-exploitation of freshwater resources and loss of freshwater ecosystems such as wetlands. As water scarcity increases, water conflicts will likely escalate. Effective design, implementation, and enforcement of watershed management policies and regulations are critical to ensuring the protection of inland freshwater ecosystems and their services. Protecting the quality, quantity, and timing of water flows, for example, requires understanding water demands for human uses, making water-use allocation decisions and tradeoffs, and enforcing those decisions. Management systems and water infrastructure also need to be designed with sufficient flexibility to enable shifts in response to changing conditions. Some specific mechanisms to help govern water resources include:

Develop a water allocation system. A water allocation system can explicitly account for climate impacts when determining the flows needed to support freshwater ecosystems within a given catchment, while also reserving water for human uses. When making allocation decisions, it is important that water needed for in-stream maintenance of freshwater ecosystems be given due consideration when managing extractive uses of water. It is also useful to consider ecosystem services, surface water and groundwater, mechanisms for water recovery in over-allocated systems, and flow protection in minimally stressed systems (Hirji and Davis, 2009a, 2009b).

RESTORING WETLANDS IN CHINA

Over the last 50 years more than two-thirds of the lakes in Hubei Province, China, were converted to polders (land reclaimed for farming and settlements), reducing wetland area by 80% and flood retention capacity by 75%. Four major floods between 1991 and 1998 caused thousands of deaths and billions of dollars in damages. Work began in 2002 to restore the wetlands in the basin, reconnecting the lakes to the Yangtze River and increasing the retention of floodwaters.

Loss of connection to the Yangtze River also limited flows for pollution dilution and fish migration. Restoration activities, including removing fishing nets to reconnect the lakes to the river, reintroducing local fish species for farming, and planting aquatic grasses, have improved water quality, increased wild fisheries species diversity and populations, and increased incomes of fish farmers.

Other benefits from the program included better access to clean water, increased biodiversity, and diversification of local economies (WWF, 2008; Nellemann and Corcoran, 2010).

Establish eco-markets. The full value of water includes its uses for social, economic, and environmental needs. Eco-markets help account for environmental values by providing a payment mechanism for ecosystem services. In Ecuador, for example, a Water Conservation Fund collects user fees from those who benefit

from the water in the Condor Bioreserves and uses these funds to support watershed management projects (Irwin and Ranganathan, 2007). In the presence of good governance, systems for water trading can be established. A system in Australia gives environmental water entitlements the same legal standing as consumptive uses, making it possible to purchase water for environmental needs (Hirji and Davis, 2009a).

Option C: Institutional Capacity

Many developing countries lack monitoring equipment and data management systems and have limited technical capacity to assess and address climate change impacts on freshwater ecosystems. Addressing these needs is considered one of the most important actions for increasing the adaptive capacity of freshwater ecosystems (Palmer et al., 2009; Le Quesne et al., 2010).

Monitoring and evaluation. Active monitoring is needed to determine baseline ecological conditions, detect changes in freshwater ecosystems in response to climate impacts, and undertake adaptive management. Monitoring (along with good governance) is also necessary to track and enforce water management strategies such as water allocations.

Technical training. Technical training of local experts is necessary to provide ongoing capacity to evaluate climate impacts on inland freshwater ecosystems. Typically, the greatest need is for training in the use of geographic information systems, climate models [e.g., PRECIS (Providing Regional Climates for Impacts Studies) System] and water supply models [e.g., Water Evaluation and Planning (WEAP) tool]. These capabilities can help local watershed managers map floodplains, analyze climate-related trends in freshwater ecosystems, and conduct other assessments.

WHAT NEEDS TO BE CONSIDERED FOR IMPLEMENTATION?

Each potential adaptation option should be thoroughly analyzed in order to select the best course of action. Typical considerations for any given adaptation option are listed in the "Adaptation options considerations" text box. Given these considerations, a mix of adaptation options may be utilized to address specific climate risks to a community, region, or nation.

ADAPTATION OPTION CONSIDERATIONS

- Benefits/co-benefits
- Cost/financing
- Effectiveness
- Feasibility
- Flexibility
- Timeframe
- Robustness to climate stressors
- Unintended costs

To succeed, strategies to protect inland freshwater ecosystems require strong institutions, well-designed policies, and ongoing monitoring and enforcement. Some other specific implementation considerations include:

- ***Governance structure and scale.*** Watershed-scale management may involve multiple stakeholders and governance levels and require modifications to trans-boundary arrangements. Coordination across different governing bodies and jurisdictions is typically needed. It may first be necessary to establish a policy framework or formal mandate to promote coordination (Irwin and Ranganathan, 2007).
- ***Costs and benefits.*** In weighing costs, it is important to consider the costs of inaction (e.g., groundwater depletion, water pollution). Many of the benefits of freshwater ecosystems cannot be readily expressed in monetary terms and thus there may be limited understanding of the importance of protecting freshwater ecosystem services. It is often helpful to use a "triple bottom line" approach involving consideration of benefits in social, economic, and environmental terms (Le Quesne et al., 2010).
- ***Relationship to larger development strategy.*** Integrating the protection of freshwater ecosystems into other related initiatives can facilitate success and help demonstrate the relevance of freshwater ecosystem

services to other development goals. For example, increasing the climate-related resilience of freshwater ecosystems also contributes to a reduction in the risks of floods, droughts, mudslides, and other water-related disasters addressed in National Disaster Management Plans. Protection of freshwater ecosystems can help support the water-resource goals of National Adaptation Programmes of Action.

- ***Uncertainties and adaptive management.*** There are uncertainties in all aspects of the adaptation process, from the climate change projections that help drive management decisions to the question of how effective a given adaptation measure will be in a particular catchment. Monitoring and adaptive management are essential tools for addressing uncertainties in the protection of freshwater ecosystems and ecosystem services (Walters, 1986; Williams et al., 2007).

Exhibit A.8.2 provides a summary of some of the major implementation considerations for options to protect inland freshwater ecosystems and ecosystem services. For each option, the table identifies key feasibility challenges in implementation; the relative cost of implementation (to other options included in the table); the level of decision-making typically involved (e.g., national, regional, or local); and other considerations including benefits, effectiveness, flexibility, unintended costs, or timeframe.

EXHIBIT A.8.2. IMPLEMENTATION CONSIDERATIONS FOR INLAND FRESHWATER ECOSYSTEMS AND ECOSYSTEM SERVICES ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Best management practices				
Reduce non-climate stressors (e.g., reduce sewage)	• Variable (depending on option, scale of action, and local context) • Generally easily scaled to needs • Most options are "no regrets"	• Variable (depending on option, scale of action, and local context) • Land-use planning costs high but provide many co-benefits • Soil conservation costs high but projects are cost-effective	• Subnational to national government/ resource agencies	• Most measures can be implemented in 1–3 years, but often require several years to show full environmental benefits
Restore degraded ecological conditions (e.g., wetland reclamation)	• Variable (depending on land ownership and scale of action) • May require engineering (e.g., river bank realignment) • Easily scaled • Most options are "no regrets"	• Variable (depending on action and land availability; may require land purchase) • Co-benefits across multiple sectors • Moderate cost to restore vegetative cover • Moderate cost of reforestation programs • Costs of restoring wetlands generally lower than cost of water treatment plants	• Subnational to national government/ resource agency decisions • May require negotiations with local land owners	• Most measures can be implemented in 1–3 years, but often require several years to show full environmental benefits

EXHIBIT A.8.2. IMPLEMENTATION CONSIDERATIONS FOR INLAND FRESHWATER ECOSYSTEMS AND ECOSYSTEM SERVICES ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option B: Watershed management policies and regulations				
Develop water allocation system that includes environmental flows	• Institutional and governance issues can be significant • May require changes in water rights and water compacts • Requires information on flow needs of particular ecosystems • Implementation more problematic during times of water scarcity • "No-regrets" action	• Low to moderate planning costs • Low administrative costs • Likely costs and tradeoffs from reduced extractive uses of water	• Most decisions at level of national government, but will require consultations among multiple stakeholders from local/community to national level • May require integration with trans-boundary decision-making	• May take many years for reforms • Allocations likely to require adjustments in response to ongoing climate changes • Long-term benefits
Develop an "eco-market" for freshwater ecosystem services	• System may be easy to develop • Low level of technical knowledge required • Most approaches are likely to require policy and legislative reforms • Institutional arrangements and governance structures unlikely to be complex, but approach may be controversial, especially during times of water scarcity • "No-regrets" action	• Costs low, primarily administrative • Beneficiaries must be able and willing to pay	• Subnational to national government/ resource agency decisions • Likely to require broad stakeholder buy-in	• Policy and regulatory changes may take several years • Long-term benefits

EXHIBIT A.8.2. IMPLEMENTATION CONSIDERATIONS FOR INLAND FRESHWATER ECOSYSTEMS AND ECOSYSTEM SERVICES ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option C: Institutional capacity				
Monitoring and evaluation	• Low level of technical knowledge required • Coordination across jurisdictions can be problematic • Ease of implementation depends on scale; large monitoring networks can be complex to design and implement	• Equipment costs (e.g., stream gauges) low to moderate, depending on scale of monitoring • Maintenance costs are low on an annual basis, but must be factored into total costs • Data management and analysis have ongoing costs; costs are low relative to total costs after initial start-up • Many co-benefits; multiple uses for data across sectors	• Decision-making by single authority rarely problematic, but decisions may also be required across multiple jurisdictions • Large monitoring networks may require trans-boundary arrangements	• Short time-frame required for start-up, except when multiple jurisdictions or trans-boundary arrangements are involved • Long-term benefits
Technical training	• Usually requires high level of technical knowledge • No governance issues, but may require special institutional arrangements	• Moderate cost to develop training materials and conduct training • May require upfront costs for computers and other special training equipment	• Local to national decision-making • Decisions rarely controversial or problematic	• Training programs can be developed and implemented quickly • Long-term benefits
Sources: Hirji and Davis (2009a, 2009b), USAID (2009), DARA (2010), World Bank (2010).				

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ADAPTATION ACTION 9 – MANAGE CRITICAL INTERDEPENDENCIES BETWEEN ENERGY AND WATER

Energy and water are closely linked. The extraction, distribution, and treatment of water require the use of energy, and the production of energy requires the use of water (Haas, 2009). As the world population increases and economies develop, demand for both energy and water will grow in the coming decades. Projected changes in climate will likely put stress on both water and energy supplies. This adaptation action focuses on the critical interdependencies between energy and water and describes potential measures that can be taken to increase the resiliency of these essential resources to the impacts of climate change.

HOW DOES MANAGING THE ENERGY/WATER NEXUS CONTRIBUTE TO CLIMATE-RESILIENT WATER MANAGEMENT?

The United Nations World Water Assessment Programme projects that demand for water in developing countries could increase by 50% by 2030 (UNESCO, 2012b). It is also likely that 40% of countries in the world, mostly low-income countries, will experience severe freshwater scarcity by 2020 (UNESCO, 2012b). The drivers of this increase in demand and scarcity include population growth, increases in irrigated agriculture, and economic development needs (UNESCO, 2012b). Population growth and rising living standards are also expected to increase global energy consumption by 50% between 2007 and 2035, with developing countries accounting for 84% of this growth (UNESCO, 2012a).

In addition to these population- and economics-driven changes in demand, climate impacts will likely further increase pressure on both water and energy. For example, compared to a reference scenario with no change in climate, global energy demand from residential heating under climate change is projected to increase by 34% and global energy demand from air conditioning is projected to increase by 72% (Isaac and van Vuuren, 2009). Climate change is likely to have equally complex impacts on the water sector. Without considering energy and water together, managers might commit to energy sources that require large water inputs, or water resources that require large energy inputs. Explicitly considering the energy/water nexus allows for a more comprehensive selection of alternatives that do not commit us to higher energy or water use.

Exhibit A.9.1 summarizes some of the linkages between the energy and water sectors. While this list is not exhaustive, it is meant to highlight the types of water uses that must be considered when expanding energy portfolios. Similar pressures on energy demand can arise from the development of deeper or more distant water resources that require substantial energy to transport, high energy input water sources like desalinization, or energy-intensive wastewater treatment technologies.

Addressing the challenge of meeting increasing energy and water demand while adapting to a changing climate will involve four interrelated efforts:

1. Reducing the energy intensity of water supply and distribution and wastewater management
2. Reducing the water intensity of energy production
3. Decoupling economic growth from energy and water consumption
4. Reducing the vulnerability of the energy and water sectors to climate impacts

Pursuing these goals will help insulate energy and water supplies from the projected impacts of climate change while also promoting development goals.

EXHIBIT A.9.1. EXAMPLES OF LINKAGES BETWEEN ENERGY AND WATER SECTORS WITH CLIMATE IMPACTS.

Energy source	Water sector linkage	Climate impact
Hydropower	Evaporative loss from large reservoirs; impacts watershed conditions	Increased variability in river flows; possible power generation restrictions due to drought
Thermal power	Power stations dependent on fresh water cooling; allocation of river flow; potential water quality impacts	Reduction in total or seasonal river flows/water availability; thermal effects on aquatic resources
Nuclear power	Plants dependent on fresh water cooling; allocation of river flow	Reduction in total or seasonal river flows/water availability; higher intake water temperatures, thermal effects on aquatic resources
Fuel wood/agricultural waste (household cooking)	Rain-fed forests; forests under competition for other land uses	Reduced fuel wood yields in some forests; hydrologic functions of forest ecosystems reduced
Biofuel crops	Rain-fed and irrigated crops; competition for land use	Changes resulting in water scarcity; multiple pressures on water for biofuel crops
Source: Adapted from Haas, 2009.		

WHAT ARE THE OPTIONS FOR MANAGING THE ENERGY/WATER NEXUS?

Below we explore options to reduce the energy intensity of the water sector, as well as existing technologies to reduce the amount of water used in energy production. These options highlight some of the strategies that can be implemented in the water, energy, and transportation sectors. Other strategies can be employed to improve efficiency and reduce vulnerability as well.

Option A: Reducing Energy Intensity of the Water Sector

Water Extraction, Treatment, and Distribution

Energy is used in the production, distribution, and treatment of water. Pumping water from aquifers, moving water through pipelines, treating water to meet applicable quality standards associated with intended end uses (e.g., to protect human health in potable uses, or desalinating water for agricultural or domestic uses), and treating wastewater all require energy. As water demand grows and conventional energy supplies become constrained (e.g., by limits on GHG emissions), new sources of energy will need to be tapped in order to supply essential water resources. This section summarizes the energy requirements of different water production alternatives, and explores the application of new energy and water management technologies to reduce the energy intensity of water management.

Pumping

As surface waters become scarce in some regions, increasing access to groundwater for domestic and agricultural uses can reduce vulnerability to climate impacts (see *Adaptation Action 1: Increase or Strengthen Water Capture and Storage*). However, extracting groundwater from aquifers requires energy. The energy required to pump groundwater ranges from 2,040 kWh per million liters from a depth of 35 m to 7,570 kWh per million liters from 120 m[13] (WBCSD, 2009). Conventional pumping systems often rely on diesel motors or electricity from the grid for power. Solar photovoltaic pumping systems have grown in popularity, particularly in rural

13. One million liters is approximately enough to supply the annual usage of 5 people in the United States, or approximately 100 people in a less-developed country (UNDP, 2006).

areas unconnected to the grid, as they eliminate the need to transport fuel and are more reliable than diesel engines (Odeh et al., 2006).

A study of diesel and photovoltaic water pumping systems in Jordan found that photovoltaic systems were more economical than diesel systems when pumping less than ~2 billion liters per year (Odeh et al., 2006). Based on this threshold, photovoltaic systems were preferred in four out of the five scenarios investigated. A broader study of groundwater pumping technologies in India compared photovoltaic-, wind-, biogas-, electric-, and diesel-driven pumps. Results of this analysis are presented in Exhibit A.9.2. While photovoltaic pumps were less costly than diesel engines and windmills, biogas- and grid electricity-driven pumps were more economical to operate than solar models (Purohit, 2007).

EXHIBIT A.9.2. ECONOMIC COMPARISON OF SELECTED GROUNDWATER PUMPING TECHNOLOGIES IN INDIA.

Technology	Unit cost of water (Rs/m^3)
Biogas	0.26
Electric motor	0.38
Solar photovoltaic	0.85
Diesel engine	1.13
Windmill	1.87
Source: Adapted from Purohit, 2007.	

Desalination

Desalination provides a new water supply source from saline waters that are otherwise unusable for most human uses (e.g., drinking, agriculture, and industrial water). As water demand grows, global desalination capacity is projected to increase 15% annually (WBCSD, 2009). However, conventional desalination technology consumes significant amounts of energy. In a reverse osmosis plant, approximately 30% of the unit production cost of desalinization is due to energy inputs (Lamei et al., 2008). In addition to the cost of energy, an oil-powered desalination plant produces 3 kg of carbon dioxide for each cubic meter of water generated (Lamei et al., 2008). Although desalination may be necessary in increasingly water-scarce regions, constraints on energy and cost will likely present an impediment to its use.

A variety of technologies are available to reduce the energy intensity and GHG emissions from desalination. Exhibit A.9.3 describes the application of photovoltaic and solar thermal technology to desalination. While the costs of solar desalination remain high relative to fossil fuel-based production, improvements in the efficiency and reductions in the cost of solar technology may make water produced by solar desalinization cost-competitive in the future (Lamei et al., 2008). Photovoltaic-driven reverse osmosis desalination plants have been constructed in Tunisia and Morocco (Papapetrou et al., 2010).

In addition to the use of solar energy to power desalination, other renewable energy sources are also available. GDF SUEZ's desalination plant in Perth, Australia, produces 140,000 m^3 of drinking water per day using electricity produced by 35 windmills (WBCSD, 2009). The development of economical renewable energy-powered desalination represents a significant opportunity to provide drinking and irrigation water in regions facing water scarcity due to climate change, population growth, and economic development. Desalination also can reduce pressure on overexploited groundwater and surface water resources.

EXHIBIT A.9.3. SOLAR PHOTOVOLTAIC AND SOLAR THERMAL DESALINATION TECHNOLOGY.

Technology consideration	Photovoltaic	Solar thermal
Function	Converts solar energy into electricity	Concentrates solar energy into heat
Use with reverse osmosis desalination	Direct	Need intermediate phase (steam turbines)
Use with thermal desalination	Not applicable	Direct
Scale of application and capacity	Small- to medium-scale; maximum 5 MW capacity (current)	Large-scale only; starts from 5 MW, 345 MW (current) to 600 MW (future)
Plants in use	Saudi Arabia, Qatar, Egypt, Turkey, and others	Kuwait, United Arab Emirates, Jordan, Spain, and others
Source: Adapted from Lamei et al., 2008.		

Water and Wastewater Treatment

Treating drinking water and wastewater is essential for protecting human health and natural ecosystems, but is an extremely energy-intensive activity. For drinking water systems, the scarcity of quality source waters, combined with heightened awareness of public health risks, is leading to an expanded application of energy-intensive drinking water treatment processes, including membranes, ultra-violet light disinfection, and/or the expanded use of chlorine and other chemicals (many of which require energy to produce).

Particularly in developing countries, centralized wastewater treatment infrastructure is often too costly and energy-intensive for widespread adoption (Massoud et al., 2009). In these cases, decentralized approaches are often preferable. One low-cost wastewater treatment option that requires little energy to operate is a constructed wetland (Massoud et al., 2009). Constructed wetlands can handle variable wastewater loadings, reduce the land area needed for treatment, and provide wildlife habitat (see the discussion in *Adaptation Action 5: Protect Water Quality* for more examples of decentralized water treatment).

A coalition of groups, including the Environment & Public Health Organization and the Asian Development Bank, has built 13 small-scale reed bed treatment systems to treat wastewater in Nepal (Gurung and Oh, 2012). These systems have been found to effectively remove pollutants at low cost. A community-scale project with the capacity to treat 50 m^3/day of wastewater has been constructed in the Sunga area of Nepal.

Onsite energy generation

As potable water treatment and distribution are highly energy-dependent, it is essential to maintain a reliable energy source in order to avoid disruptions in treatment and service. A number of opportunities exist to generate energy onsite for use in water treatment. Even where these onsite options are not utilized as a primary energy source, backup generators can be useful to provide power during periods when grid-based supplies may be disrupted by storm events or other factors. Where practical, such backup power may be provided by renewable, low GHG-emitting energy sources.

At wastewater treatment facilities, one cost-effective option for onsite power generation is the use of microturbines for small-scale hydropower generation at the outfall. New facilities can also incorporate high-energy efficiency design standards, as well as incorporating renewable energy facilities into plant design.

Another opportunity in the wastewater treatment sector is the generation of energy from waste. Turning a waste product into an energy source has the potential to both improve waste management and offset energy production from fossil fuel-based sources. This approach is being implemented in a number of areas. A two-phase anaerobic digestion plant that treats municipal sewage and produces biogas was developed as a pilot plant in Yogakarta, Indonesia (Passio et al., 2012). In Slovenia, organic waste was combined with municipal sludge and processed by anaerobic co-digestion in order to produce biogas (Zupančič et al., 2008). The experiment was able to reduce GHG emissions, replace natural gas use with biogas, and increase energy production by 130% (Zupančič et al., 2008). As growing, urbanized populations demand more energy and produce more waste, options that can both produce low-carbon energy and manage wastewater represent essential innovations.

Option B: Reducing the Water Intensity of Energy Production

Both the extraction and production of fuels, and the generation of electricity use water. As energy demand grows and water supplies become increasingly constrained by competition from multiple uses, the water efficiency of energy production must improve. This section explores the water intensity of existing energy sources and examines available technologies to reduce water use in the energy and transportation sectors.

Water Intensity of Energy Supplies

The production of most types of fuel consumes water. Exhibit A.9.4 presents the water requirements for producing a variety of fossil-based and alternative fuels in the United States.[14] These figures indicate the range of water inputs required for the production of fuels. Biofuel production is particularly water-intensive due to the irrigation required to grow biofuel crops.

EXHIBIT A.9.4. WATER-USE EFFICIENCY OF EXTRACTING OR PRODUCING FUELS.

Fuel source	High water efficiency (gallons/MBtu)	Low water efficiency (gallons/MBtu)
Natural gas	3	–
Synfuel-coal gasification	11	26
Synfuel-tar sands	15	38
Synfuel-oil shale	20	50
Coal	41	164
Petroleum/oil	1,200	2,420
Corn-ethanol	2,510	29,100
Soy-biodiesel	14,000	75,000
Source: Adapted from Younos et al., 2009.		

14. These figures include water used in the operation of mines and mining equipment, production of feedstocks, and refining. Water that is returned to its source after use is not considered "used" in these figures. Natural gas production here refers to conventional gas drilling, not hydraulic fracturing.

In addition to producing or extracting fuel, the generation of electricity also requires water. Exhibit A.9.5 illustrates the water-use efficiency of various electricity generation methods in the United States.[15] These figures show that fossil fuel-based generation (e.g., coal, natural gas, oil) and nuclear generation are particularly water-intensive.

EXHIBIT A.9.5. WATER-USE EFFICIENCY OF POWER GENERATION.

Generation method	High water efficiency (gallons/MBtu)	Low water efficiency (gallons/MBtu)
Hydroelectric	20	N/A
Geothermal	130	N/A
Hydrogen	143	243
Solar thermoelectric	230	270
Fossil fuel thermoelectric	1,100	2,200
Nuclear	2,400	5,800
Source: Adapted from Younos et al., 2009.		

In a carbon-constrained future, renewable electricity generation will need to increase. Renewable technologies vary with regard to the amount of water needed to generate a given quantity of electricity. Exhibit A.9.6 focuses on the water consumption of renewable energy technologies as compared to coal and gas-fired generation. Wind and solar photovoltaic are the least water-intensive and both provide water savings relative to fossil fuel-based generation.

EXHIBIT A.9.6. WATER CONSUMPTION IN ELECTRICITY GENERATION.

Generation methods	Water consumption (kg/kWh)
Wind	1
Solar photovoltaic	10
Geothermal	12–300
Hydroelectric	36
Coal	78
Gas	78
Source: Adapted from Evans et al., 2009.	

Options for thermoelectric generation

Thermoelectric electricity generation driven by coal, natural gas, and nuclear power will most likely continue to supply a significant portion of electricity for the foreseeable future. These generation methods traditionally use significant amounts of water for cooling. One way to reduce the water intensity of electricity generation is to switch from wet cooling to dry cooling of power plants.

Open cycle or once-through cooling systems extract water from the environment, pass it through the cooling system, and return the water to the source. In wet-cooled once-through plants, approximately 99% of the water is returned to the environment and only 1% of the extracted water is consumed (Smart and Aspinall, 2009). Technologies to reduce the water consumption or impact of thermoelectric generation include:

15. These figures include water used in the production of electricity. Water that is returned to its source after use is not considered "used" in these figures.

- ***Closed-cycle wet cooling.*** These systems discharge heat through a condenser and cooling tower. Closed-cycle wet cooling consumes more water than once-through systems (due to evaporative loss), but has a minimal impact on the water source as it does not return warm water to the environment, nor does it extract as large a volume of raw water from the environment.
- ***Dry cooling.*** These systems are more expensive and less efficient than wet systems, but eliminate water withdrawals (Webber, 2008; Smart and Aspinall, 2009; Zhai and Rubin, 2010). These systems cool the exhaust steam by passing the heat directly to an air-cooled condenser. The capital costs of a dry cooling system make up 12% of total plant capital costs compared to 5% for a closed-cycle wet-cooling system (Zhai and Rubin, 2010). In addition, dry cooling reduces net plant energy efficiency and increases electricity costs (Zhai and Rubin, 2010).
- ***Thermal efficiency.*** Supercritical and ultra-supercritical[16] plants consume 10% and 26% less cooling water, respectively, than subcritical plants (Zhai and Rubin, 2010).

An additional consideration for water use in power plants is the effect of carbon capture and storage (CCS) technology. CCS technologies capture and store GHGs from power plants before they are emitted into the atmosphere. While the deployment of CCS technology may be a necessary mitigation strategy for reducing GHG emissions, the application of CCS at power plants lowers net plant efficiency and increases consumptive cooling water use by 83% to 91% (Zhai and Rubin, 2010).

Despite the challenges presented by transitioning to dry cooling, steps are already being taken to reduce water use in electricity generation. Eskom, which produces electricity in South Africa, has reduced water use by 200 million liters per day by using dry cooling and by desalinating polluted mine water for use at its power stations (WBCSD, 2009).

Water Intensity of Transportation

Transportation presents another sector where options can be implemented to enhance energy efficiency and reduce related water use. For example, biofuel production is particularly water-intensive (see Exhibit A.9.6). A vehicle fueled by ethanol consumes 40 gallons of water per mile travelled compared to 0.6 gallons per mile for a gasoline-powered vehicle (Hoyle, 2008). Transitioning from biofuels made from corn or soybeans, which are water-intensive and potentially compete with food crops, to lignocelluosic biofuel feedstocks (e.g., switchgrass) can reduce water use (Dominguez-Faus et al., 2009). In addition, producing biofuels from algae is particularly efficient. Algal biofuels can be produced on marginal land using wastewater or seawater, which reduces the freshwater inputs to biofuel production (Schenk et al., 2008).

It is also possible to reduce the water intensity of conventional fuel production. A Canadian refinery operated by Petro-Canada is using wastewater from a municipal water treatment facility as feed water for its petroleum refining process, eliminating the need for additional freshwater withdrawals (WBCSD, 2009).

Electric vehicles also pose a concern related to the water intensity of available fuels. While the use of electricity to power vehicles can reduce GHG emissions, it can increase the water intensity of operating those vehicles. Depending on the source of electricity, electric vehicles can use up to 11 gallons of water per mile compared to 0.6 gallons per mile for gasoline-powered vehicles (Hoyle, 2008).

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16. Supercritical steam generators operate at such high pressures (3,200 psi or 22 MPa) that boiling ceases to occur, resulting in slightly less fuel use and less water loss. The first supercritical generator began operation in 1957. The much more recent ultra-supercritical technology operates at even higher temperatures and pressures, further increasing thermodynamic efficiency.

WHAT NEEDS TO BE CONSIDERED FOR IMPLEMENTATION?

Each potential adaptation option should be thoroughly analyzed in order to select the best course of action. Typical considerations for any given adaptation option are listed in the "Adaptation options considerations" text box. Given these considerations, a mix of adaptation options may be utilized to address specific climate risks to a community, region, or nation.

ADAPTATION OPTION CONSIDERATIONS

- Benefits/co-benefits
- Cost/financing
- Effectiveness
- Feasibility
- Flexibility
- Timeframe
- Robustness to climate stressors
- Unintended costs

The critical interdependencies between energy and water use and the vulnerabilities of both sectors to the impacts of climate change require that mitigation and adaptation options account for these linkages. Economic growth in developing countries and the transition to low-carbon energy sources in the coming decades presents an opportunity to adopt smart development strategies that can meet these challenges. Low-carbon, low-water use energy sources can be deployed to meet growing energy demands. Energy-efficient water distribution and treatment systems can be powered by low-carbon electricity. Efficiency in both sectors can be improved by conservation and reuse strategies that can offset growing demand and limited supply. All of these steps can be taken with an eye toward the projected impacts of climate change so as to reduce the vulnerability of these sectors in the future.

Exhibit A.9.7 provides a summary of some of the major implementation considerations for options to managing water-energy interdependencies. For each option, the table identifies key feasibility challenges in implementation; the relative cost of implementation (to other options included in the table); the level of decision-making typically involved (e.g., national, regional, or local); and other considerations including benefits, effectiveness, flexibility, unintended costs, or timeframe.

EXHIBIT A.9.7. IMPLEMENTATION CONSIDERATIONS FOR MANAGING WATER-ENERGY INTERDEPENDENCY ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Renewable powered water pumps	• Wind and solar powered pumps eliminate need to transport fuel or extend electricity grid • Technology is not significantly more complex than conventional pumps	• Low to high, depending on power source • Cost-competitive with conventional pumps for low volumes	• Decision can be made at household or community level • Higher-level decisions can incentivize or provide technical/ financial resources	• Technology can be adopted quickly without new infrastructure • Widespread conversion likely to take time
Option A: Renewable powered desalination or other treatment processes	• Significant technological expertise required for construction and O&M	• High cost relative to fossil-fuel powered desalination • Cost likely to fall as solar/wind electricity generation costs decrease • High capital costs	• Municipal/national level decision due to high financial/technological/ administrative demands	• Long-term option due to construction time and time needed to pay back capital costs

EXHIBIT A.9.7. IMPLEMENTATION CONSIDERATIONS FOR MANAGING WATER-ENERGY INTERDEPENDENCY ADAPTATION OPTIONS.

Option	Feasibility	Cost	Level of decision	Other considerations
Option A: Energy-efficient water and wastewater treatment	• Constructed wetlands and anaerobic digester technology require some expertise	• Constructed wetlands are lower cost than conventional wastewater treatment • Anaerobic digesters add cost but can produce energy, offsetting increased costs	• Decision typically made at the local government/ regional government level • National financial incentives and regulatory reform may incent adoption	• Short- to medium-term adoption • Benefits accrue over medium- to long-term
Option B: Water-efficient electricity generation	• Wind and solar generation is well-established and less water-intensive than fossil fuel-based generation • Dry cooling technology for fossil-fuel generation is well-established	• Cost of wind and solar generation generally remains higher than fossil fuel-based generation, although renewable costs continue to fall • Dry cooling of fossil-fuel generation reduces water intensity but increases costs	• Household-scale solar can be adopted by individuals • Utility-scale renewable generation is adopted at the community/regional level • Dry cooling for fossil-fuel generation can be mandated by regional/ national policies • National incentives/regulations can incent adoption of all technologies	• Small-scale solar can be adopted in short-term • Utility-scale renewable projects and dry cooling require time for regulatory approval and construction
Option B: Water-efficient transportation fuels	• Less water-intense biofuels are still in research and development phase • Water-efficient electricity generation is required for effective transition to electric vehicles	• Commercial cost of water-efficient biofuels is still uncertain	• Adoption of water-efficient biofuels likely requires national incentives and/or regulatory reform	• Long-term transformation of transportation sector required

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ADAPTATION ACTION 10 – STRENGTHEN WATER GOVERNANCE

How water managers choose to govern their water resources has critical influence on the sustainability, effectiveness, and practicality of any given adaptation action. Adaptation actions that strengthen water governance complement and enhance other adaptation actions, such as those described in the previous sections of this appendix. In addition, the social, political, and economic context (i.e., the political economy) surrounding some of these other adaptation actions often require a degree of governance intervention in order for the actions to have a realistic chance of success.

In general, strong governance is important for adaptation actions – including those in the water sector – for the following reasons:

- Weak governance frameworks (i.e., those that lack transparency and accountability, are corrupt, and feature ineffective or fragmented institutions and policies) are an obstacle to the creation and implementation of sustainable adaptation actions.
- The political economy of the communities and countries in which adaptation is occurring shapes the feasibility and comparative effectiveness of climate-related interventions.
- Adaptation actions present a window of opportunity to promote governance-strengthening initiatives. This can create a stronger enabling environment for climate-resilient development.

This adaptation action focuses on strengthening water governance to assist in climate-resilient water management. A menu of potential options for strengthening water governance is provided below and key considerations for implementing these options are also identified.

HOW CAN STRENGTHENING WATER GOVERNANCE CONTRIBUTE TO CLIMATE-RESILIENT WATER MANAGEMENT?

In many developing countries, poor governance limits the availability of options for improving water resources management and thus enhancing climate resilience. In general, poor governance is evidenced through the following:

- Weak or ineffective policies and legal frameworks (e.g., for allocating water)
- Unenforced laws or regulations
- Weak or ineffective institutions and lack of institutional coordination
- Lack of transparency and accountability in decision-making
- Lack of effective and representative stakeholder engagement in decision-making

These governance challenges are prevalent throughout the water sector in many countries. Actions that address these challenges in the water sector will enhance the effectiveness of other adaptation actions in the sector and therefore increase climate resilience.

WHAT ARE THE OPTIONS FOR STRENGTHENING WATER GOVERNANCE?

Strong water governance at all levels, from the local community up to the national government (and even across national boundaries), is integral to enhancing climate resilience in the water sector. There are numerous options at all levels, ranging from institutional and legal reforms to sectoral governance reforms that support adaptive capacity.

Institutional and legal reforms in developing countries can create environments that enable successful adaptation actions in the water sector, but they can be challenging to implement. For example, in some developing countries, water consumption is subsidized by the government, so individuals, organizations, and private companies have little incentive to moderate water use; repealing government subsidies for water consumption can help improve climate resilience by reducing excess stress on water resources. However, the political environment that most water managers and development practitioners encounter is often not conducive to such institutional and legal reforms. In addition, many local adaptation options are impacted by disconnects between informal (e.g., practices based on custom) and formal (e.g., legal) water governance mechanisms. It is therefore important to identify and emphasize capacity-building reforms that can enhance adaptive capacity regardless of political, social, and economic conditions (e.g., improving the effectiveness of public engagement to mitigate challenges associated with overlapping legal mandates; see box, "Institutional support and strengthening program in Jordan").

INSTITUTIONAL SUPPORT AND STRENGTHENING PROGRAM IN JORDAN

Jordan is working with USAID on an Institutional Support and Strengthening Program to create an enabling environment for adaptive measures in the water sector by addressing legal and institutional barriers. Activities include – among other things – conducting institutional assessments that analyze key sector constraints to water sector management, assessing the value of water to provide decision-makers with a common reference for evaluating tradeoffs in the sector, and strengthening water legislation by assessing options and barriers to addressing deficiencies in current laws and regulations.

Source: ISSP, 2013.

The remainder of this section focuses primarily on capacity-building reform.[17] The potential effectiveness of options for strengthening water governance vary across countries because of location-specific environmental, political, social, and economic characteristics (e.g., differences in governmental processes and cross-governmental cultural norms). Nevertheless, the following options can generally be considered for strengthening water governance, and be modified, as necessary, to address local conditions.

Option A: Decentralize Water Decision-making

Decentralizing water decision-making involves delegating responsibilities for making decisions about water management to lower levels of government (e.g., the municipality level), the private sector, or nongovernmental community organizations (e.g., local water boards), and supporting this lower-level execution.[18] Bottom-up approaches to decision-making build on the experiences and knowledge of local individuals and groups, which is important for ensuring that water management decisions are appropriate given local conditions (Uhlendahl et al., 2011). According to the UNDP Water Governance Facility, the catchment is an appropriate scale at which water management decisions should be made (UNDP, 2013a).

Formal decentralization of water decision-making often requires legislation at the national level. Specific activities that can enhance the effectiveness of efforts to decentralize water decision-making include:

17. The options identified in this section are based in part on options identified by UNDP's Water Governance Facility (UNDP, 2013a).

18. It is important that the delegation of decision-making responsibilities to lower levels not be simply pro forma. Effective decentralization also involves providing implementation support to the responsible lower-level governments or other entities.

- ***Ensure transparency when delegating responsibilities to lower levels of government, the private sector, or other groups***. Transparency is critical for protecting the decision-making processes from being controlled by powerful local groups that might wrongfully claim authority and take advantage of poor or underprivileged stakeholders who are typically marginalized (Uhlendahl et al., 2011). Lack of transparency can foster corruption in water resources management, which creates barriers to increased climate resilience and improved livelihood in general. Improving transparency in governance is a key aspect of preventing corruption in water management (see text boxes, "Training for local stakeholders in Kenya" and "Enhancing transparency and accountability in Zambia through water watch groups").
- ***Increase stakeholder participation***. Involving a wide range of stakeholders (including water user associations, farmers' cooperatives, women's groups, and village communities) in water management results in better informed decision-making, because local stakeholders are most aware of the applicability of different reforms in a given area. Studies suggest that increasing local stakeholder participation can also enhance implementation of policies or reforms because more people and groups have assumed ownership of the management processes (e.g., Cosgrove and Rijsberman, 2000; Ako Ako et al., 2010). It is important for stakeholder participation to be cross-sectoral to ensure that water management decisions take into account the demands and impacts of agricultural policies, urban infrastructure, and energy consumption, among other considerations (see text box, "Surveying stakeholder perceptions of water governance in Uganda").
- ***Improve stakeholder access to information.*** Making information about issues such as water resources management, water demand, and climate change impacts available and accessible to stakeholders will help improve the quality of their engagement in the stakeholder participation processes (UNECE, 2009). It is important that the information not only be made available to stakeholders but also be provided in a manner and format that is accessible to the stakeholders so that they can more easily use the information in their decision-making (see text box, "Educating stakeholders in the Santiago River Basin in Mexico").

TRAINING FOR LOCAL STAKEHOLDERS IN KENYA

Water resources in the Maturu-Luandeti region of Kenya are managed by a committee of elected members. The committee members are all trained in a range of managerial functions, including general leadership and basic financial management (e.g., bookkeeping). These trainings are designed to help ensure that local water governance is accountable and transparent.

Source: IRC, 1997.

ENHANCING TRANSPARENCY AND ACCOUNTABILITY IN ZAMBIA THROUGH WATER WATCH GROUPS

To help protect against corruption in the water sector at the local level, Zambia has established a program to support water watch groups that serve as the local "eyes and ears" of the national water regulatory bodies and provide a voice for local stakeholders. Members of these local groups are appointed and drawn from wide-ranging backgrounds. They serve for one year, during which time they are responsible for overseeing water providers and receiving, coordinating, and addressing consumers' complaints and concerns. The groups have been very successful in increasing local awareness of water governance issues and reducing the prevalence of vandalism.

Option B: Adopt Catchment Management Approaches

Cooperation across catchments[19] can support a wide range of water management activities, including information collection efforts, land use planning, climate data analysis, and evaluation of regional non-climate stressors.

Watersheds often extend beyond local and national political boundaries. For example, according to the International Network of Basin Organizations, there are 263 large, transboundary river basins across the globe. In some locations, these basins cover the majority of the area. For example, transboundary basins account for more than 60% of Africa's total continental area, and approximately 40% of the world's population resides in transboundary basins (GWP-INBO, 2009). Because of the transboundary nature of most watersheds, managing water resources at the catchment scale can lead to better decision-making and more equitable allocation of water.

Specific activities that can enhance catchment management approaches include:

- ***Negotiate transboundary water agreements.*** According to the United Nations UN-Water program, nearly 300 transboundary water agreements have been negotiated and signed since 1948 (UN-Water, 2008). These agreements provide for equitable sharing of the responsibility for and benefits of water resources at the catchment scale. A key first step in implementing transboundary water agreements is to develop a catchment action plan. More information on developing catchment action plans is available in the Global Water Partnership and International Network of Basin Organizations' *A Handbook for Integrated Water Resources Management in Basins* (GWP-INBO, 2009).

SURVEYING STAKEHOLDER PERCEPTIONS OF WATER GOVERNANCE IN UGANDA

In 2006, as part its efforts to improve transparency and accountability in the water sector, the Uganda Ministry of Water established a working group dedicated to improving water governance. The Good Governance Sub-Sector Working Group, which included participants from a wide range of stakeholder groups, developed a set of recommended measures for promoting and monitoring transparency, accountability, and other good governance indicators for incorporation into a national Governance Action Plan for the water sector. The working group also initiated a National Baseline Survey to collect data on water sector stakeholders' perceptions of how water is managed in the country. This study has formed the basis for a number of the country's ongoing efforts to improve governance.

EDUCATING STAKEHOLDERS IN THE SANTIAGO RIVER BASIN IN MEXICO

In 2010, the Santiago River Watershed Council in Mexico released the *Guide for Educators, Discover a Watershed: Santiago River*, which it uses to educate water sector stakeholders about environmental degradation and water management. The program objective is to improve decision-making at the local level by building stakeholder capacity to understand and address challenging issues related to water management. The guide is particularly targeted at educators and policymakers, so that they can learn how to communicate about these issues with their various audiences.

Source: World Water Forum, 2012.

19. Note that catchments often cross national boundaries. As a result, transboundary catchment planning and management is critical for strengthening water governance. However, there are many activities that can be implemented at the domestic level. The activities described in this section are focused on domestic improvements to catchment management that can support transboundary efforts.

- ***Collect and manage information about water use across the catchment***. Information generation and management are often critical to the development of rational and effective policies, and this is often an elusive commodity in developing countries. For example, information on how many groundwater wells are in use in a catchment and the average amount of water withdrawn from each well is fundamental for understanding water usage patterns, determining mechanisms for improving efficiency, and creating and implementing effective pricing structures (see text box "Transboundary Diagnostic Analysis in Cubango-Okavango River Basin in Angola, Namibia, and Botswana").

- ***Establish catchment management agencies***. Establishing and supporting organizations that are responsible for monitoring and evaluating climate and non-climate stressors related to development can improve the effectiveness of decision-making at the catchment scale (see text box "Integrating water governance across levels of government in Panama"). These organizations can also be delegated responsibilities for implementing basic principles of transboundary management, including reviewing development plan designs and resolving disputes. For example, in Kenya, subnational Catchment Area Advisory Committees and Water Services Boards serve as the national government's local water management representatives and are responsible for monitoring community water user associations and water services (KWAHO, 2009).

  The catchment management agencies should be carefully sized to match an appropriate level of governance. In South Africa, legislation in 1998 led to the delegation of water-related decision-making to subnational catchment management agencies. However, efforts to improve catchment-level water management in the country were impeded by a decision by the national government to establish only nine such agencies, a number that was considered by many stakeholders to be too small, and many stakeholders disengaged from planning discussions as a result of this decision (Jonker et al., 2010).

TRANSBOUNDARY DIAGNOSTIC ANALYSIS IN CUBANGO-OKAVANGO RIVER BASIN IN ANGOLA, NAMIBIA, AND BOTSWANA

In 1994, Angola, Namibia, and Botswana established the Permanent Okavango River Basin Water Commission (OKACOM) to coordinate sustainable water resources management in the Cubango-Okavango river basin. One of OKACOM's primary functions is determining how to allocate water resources across different sectors and political boundaries. To inform decisions about water allocation in the region, OKACOM conducted a transboundary diagnostic analysis that evaluated a range of water-use scenarios to determine their potential regional ecological, social, and macro-economic outcomes. This analysis formed the basis for the development of a Strategic Action Program that the Commission uses to guide its decision-making.

INTEGRATING WATER GOVERNANCE ACROSS LEVELS OF GOVERNMENT IN PANAMA

To help improve local stakeholder participation and strengthen overall water governance in the Panama Canal basin, the country has established six advisory councils and 30 local committees. The local committees include representatives of existing community organizations, thus providing each local committee with a strong understanding of local conditions and practices. These committees report to the advisory councils, which coordinate activities across their respective local committees. Each council has an associated technical group that provides assistance to the local committees on engineering, environmental, economic, and legal issues. The councils report to the Panama Canal governing body.

Sources: Panama Canal, 2012; World Water Forum, 2012.

- ***Establish networks and mechanisms for sharing experiences across a catchment.*** Developing a network of skilled water resource managers throughout a catchment can help improve decision-making, and can increase rapid response capabilities in the face of climate-related events, such as floods. It is important that appropriate mechanisms for sharing experiences (e.g., regular meetings) be in place (see text boxes "Mechanism for coordination on water management in Uganda" and "Coordinating information sharing in the Mekong River Basin").

Option C: Clarify Institutional Roles and Responsibilities and Develop Coordination Mechanisms

Determining which institution(s) make decisions about water resources, and when and how, is a critical aspect of water management. Effective water governance necessarily involves establishing and maintaining clear and transparent roles and responsibilities for the institutions that are accountable for making these decisions. Specific activities that can help ensure appropriate delineation of roles and responsibilities include:

- ***Promote legislation that clearly defines the roles and responsibilities of different institutions.*** Establishing and maintaining clear rules for who is responsible for determining water allocation across and within sectors is an essential component of good water governance. Ensuring that the designated institution is operating effectively and transparently will help ensure equitable treatment of competing demands for water resources across various sectors.
- ***Develop and support mechanisms that enable coordination across institutions.*** Effective coordination across institutions (e.g., across levels of government) is a critical element of strong water governance. Developing and supporting mechanisms that allow for effective coordination (e.g., regular and structured consultations) can help bridge gaps between policy development and implementation at the community level (UNECE, 2009). These mechanisms can also improve water allocation

MECHANISM FOR COORDINATION ON WATER MANAGEMENT IN UGANDA

Uganda is working on a number of measures to decentralize decision-making in the water sector and increase stakeholder participation. To help improve coordination across the numerous bodies currently involved in governing the country's water resources, the more than 180 nongovernmental water-related organizations in the country have come together to form the Uganda Water and Sanitation Network. In addition to coordinating information and activities across the nongovernmental organizations, the network provides a key mechanism for engagement between local communities and a wide range of other stakeholders.

Source: UNDP, 2011.

COORDINATING INFORMATION SHARING IN THE MEKONG RIVER BASIN

The lower Mekong River Basin is home to more than 60 million people. This large population imposes significant demands on the Mekong River's water. In addition, the region is home to a number of large hydroelectric projects that divert considerable quantities of water, and a range of agricultural activities that also compete for water resources. To help manage the river's resources, Cambodia, Laos, Thailand, and Vietnam established the Mekong River Commission in 1995. Among other projects, the commission is working with a range of stakeholders to develop a database of knowledge relating to climate change and adaptation measures in the region. The database is designed to facilitate information exchange and networking among various water sector stakeholders, and to improve awareness of climate and water governance issues.

Sources: GIZ, 2013; MRC, 2013.

coordination across government agencies. The USAID *Governing for Resilience: An Annex to the USAID Climate-Resilient Development Framework* (USAID, Forthcoming) provides more information on coordination mechanisms for improving governance to enhance climate resilience.

- ***Identify institutions and organizations that are responsible for collecting, managing, and applying climate data.*** As noted above, increasing knowledge about how and where water resources are used throughout the basin is a key aspect of strengthening water governance. Designating a government body, community organization, private company, or other entity as the party responsible for collecting and managing information about such issues as wellhead locations and operation can help inform decision-making. It is important to note that designating responsible bodies is not sufficient to ensure effective climate data collection and management; the responsible bodies must have the capacity and funding to perform these activities. Ensuring they have sufficient capacity can involve investing in and deploying additional monitoring equipment; training staff in data collection and management, and providing technical assistance in analyzing and interpreting climate data (see text box "Trainings for water user associations in the Great Ruaha River Basin in Tanzania").

TRAININGS FOR WATER USER ASSOCIATIONS IN THE GREAT RUAHA RIVER BASIN IN TANZANIA

The Great Ruaha River Basin is home to six million people in Tanzania. As population and development increased through the 20th century, demands on the region's water resources became unsustainable; by the early 1990s, impacts from the degradation of the river's resources began to become more evident. Local water users associations were established to help improve water management in the river basin. Association members attended month-long capacity building training sessions that provided lessons in restoring water source catchments, negotiating agreements with agricultural users to regulate their water consumption, and enforcing water policies.

Source: WWF, 2012.

- ***Establish and support institutions that explicitly account for climate change.*** Improving water governance to more effectively manage water resources can involve (1) supporting water-related institutions and governance systems that already take explicit account of climate change, and (2) encouraging the ones that do not take explicit account of climate change to do so. This might involve such things as utilizing more adaptive, flexible, and robust approaches to water management, incorporating climate data into water policies, and looking more carefully at flow and demand data to inform planning. Cook et al. (2011) identify a set of principles or characteristics that are important for climate adaptive institutions and Hill (2013) discusses building adaptive capacity through adaptive governance. The themes for adaptive institutions and decision-makers include an environment that supports the ability to adapt, having sufficient resources and an ability to manage it flexibly to react to climate change, being forward thinking and learning by doing, collaborating with other institutions and leveraging collective learning, evaluating its actions and refining them, and incorporating adaptation in all its operations (Cook et al, 2011; Hill, 2013).

Option D: Increase Compliance Assistance and Enforcement Capacity

Communities sometimes lack capacity to comply with water laws and regulations (e.g., for reducing water pollution, encouraging water conservation, or demand management). This is often due to a lack of technical training and poor outreach about the laws and regulations. In addition, in many developing countries, insufficient capacity among national and local governments leads to poor enforcement of water laws and regulations, often in the form of insufficient or inequitable compliance inspections. A key component of compliance is reporting – effective reporting requires sufficient and appropriate mechanisms to verify compliance and monitor performance (UNECE, 2009). Citizen education efforts, public relations campaigns,

financial support for expanding enforcement personnel, and training of enforcement personnel are all potential solutions to increase compliance.

WHAT NEEDS TO BE CONSIDERED FOR IMPLEMENTATION?

Each potential adaptation option should be thoroughly analyzed in order to select the best course of action. Typical considerations for any given adaptation option are listed in the "Adaptation option considerations" text box. Given these considerations, a mix of adaptation options can be utilized to address specific climate risks to a community, region, or nation.

ADAPTATION OPTION CONSIDERATIONS

- Benefits/co-benefits
- Cost/financing
- Effectiveness
- Feasibility
- Flexibility
- Timeframe
- Robustness to climate stressors
- Unintended costs

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