WATER SECTOR CLIMATE CHANGE ADAPTATION GUIDANCE NOTE

IsDB
البنك الإسلامي للتنمية
Islamic Development Bank

Acknowledgments

The preparation of the Water and Sanitation Sectors guidance note was led by the IsDB Climate Change Division with input from water and sanitation sector experts at the Islamic Development Bank and partner institutions.

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Disclaimer

1. About this Guidance Note

This water sector guidance note was prepared by the World Resources Institute (WRI) for the Islamic Development Bank (IsDB) to enable IsDB project teams to integrate information on climate risks into project design. It applies to water sector projects involving physical assets. For the purposes of this note, "water sector" does not include hydropower or irrigation projects, which will be included in subsequent guidance documents. Instead, it encompasses the following two categories:

- Water supply projects
  - Water resources extraction and conveyance structures
  - Water treatment facilities (including desalination)
  - Treated water storage (storage tanks and basins)
  - Distribution networks
- Sanitation projects
  - Sewerage and piped collection networks
  - Sewage treatment facilities
  - Small-scale sanitation systems (pit latrines and septic tanks)

After a brief background on projected climate changes in the regions where IsDB operates and their projected impacts on the water sector (Section 2), Section 3 explains the purpose of this note within a broader climate risk management process. It describes the steps involved in managing a project's climate change risks—beginning with climate risk screening, followed by project impact and adaptation assessments, and ending with project implementation. Section 4 then describes the process of determining potential climate impacts on water sector projects and identifying adaptation options to address those impacts. Section 5 presents an approach to evaluate adaptation options, and Section 6 concludes with two case studies that demonstrate how this approach may be applied in practice.

2. Background: Climate Change and the Water Sector

In 2017, a total of $3.9 billion was approved from IsDB's Ordinary Capital Resources. (IsDB 2017). Of the total, 71.4 percent supported infrastructure projects, and 21.4 percent of infrastructure expenditures supported projects in the urban development and services sector, which includes urban water and sanitation infrastructure (IsDB 2013). 18.4 percent of net approvals went to agricultural and rural development, which includes water resources and environmental projects (IsDB 2017).

IsDB operates in four core regions: the Middle East and North African, sub-Saharan Africa, Europe and Central Asia, and Asia and Latin America.[1] Observed and projected climate changes vary across these regions.

Throughout much of Africa, temperatures have increased by at least 0.5°C over the last 50 to 100 years, with minimum temperatures rising faster than maximum temperatures. Much of the region lacks sufficient data to draw conclusions about trends in annual precipitation. However, in the western and eastern Sahel regions, annual precipitation has likely decreased, and in parts of eastern and southern Africa, it has likely increased. In terms of model projections, it is likely that land temperatures over Africa will rise faster than the global average, particularly in the more arid regions. There is considerable uncertainty regarding projected precipitation patterns in sub-Saharan Africa, but there is greater model agreement that precipitation will increase in east Africa and decrease in north and southwest Africa. Across the continent, climate change is expected to exacerbate existing water stress (Niang et al. 2014).

In the past century, much of Asia has experienced warming trends and increasing temperature extremes. There is little agreement on projected precipitation patterns at a subregional scale, but under a higher warming scenario (Representative Concentration Pathway [RCP] 8.5), precipitation is likely to increase at higher latitudes by the middle of the 21st century, and in parts of eastern and southern Asia by the late 21st century. Water scarcity is expected to be a major challenge for most of Asia due to increased water demand and poor water management (Hijioka et al. 2014). In Europe, future climate projections vary regionally, with projected temperature increases throughout the region, precipitation increases in northern Europe, and precipitation decreases in southern Europe. Across the continent, climate projections indicate a marked increase in heat waves, droughts, and heavy precipitation events (Kovats et al. 2014).

Lastly, significant trends in precipitation and temperature have been observed in Central America and South America, but the patterns vary regionally, with increasing trends in annual rainfall in southeastern South America and decreasing trends in Central America and central-southern Chile. Increased warming has been observed throughout the region, with the exception of the Chilean coast. Increases in temperature extremes have been measured in Central America and most of tropical and subtropical South America, while more frequent extreme rainfall in southeastern South America has produced more landslides and flash floods. Under the RCP 8.5, climate models project a mean reduction of 10 percent in annual precipitation for Central

America (with a reduction in summer precipitation) by 2100, a decrease of 10 percent for tropical South America east of the Andes, and an increase of 15 to 20 percent for southeastern South America. One major concern is the melting of the Andean cryosphere, which is altering the seasonal distribution of streamflow. Possible precipitation reductions combined with higher evapotranspiration could lead to water shortages, particularly for cities highly dependent on glacial outflows (Magrin et al. 2014).

Changes in mean climate conditions, climate variability, and climate extremes could impact the water sector in diverse ways, including direct and indirect physical impacts and a variety of nonphysical impacts (Charles et al. 2009). Direct physical impacts could be event-driven or more gradual. For instance, flash flooding or tropical cyclones could physically damage assets and equipment or disrupt power supplies. At the same time, longer-term shifts in climate patterns, like sustained higher temperatures, could diminish the quantity or quality of available freshwater resources (UNEP 2017). In addition to the many potential direct physical impacts, climate change could indirectly disrupt water sector operations by impacting transport links and worker mobility, for example.

A variety of nonphysical impacts, including market, legal, and reputational impacts, could follow from physical changes. Heat waves, for example, could prompt short-term spikes in demand for service (Charles et al. 2009). Additionally, any climate impacts that disrupt service could have legal implications if disturbances prevent service providers from fulfilling regulatory or contractual obligations. Service disruptions and other consequent failures could also have damaging reputational impacts for service providers. Changing conditions could also lead to revised regulatory requirements. For example, diminished water quality in receiving waters could lead to more stringent treatment requirements for discharged wastewater (US EPA 2015). Potential climate impacts are discussed in greater detail in Section 4.

At the same time, a variety of nonclimate stressors, including population growth, rapid urbanization, land-use change, agricultural demand, and economic growth, also present significant challenges to the water sector (ADB 2017). Population and economic growth increase demand for water, while also putting additional strain on water quality. In many cases, the climate impacts described above will exacerbate existing or worsening nonclimate stressors (USAID 2014).

FIGURE 1: CLIMATE RISK MANAGEMENT PROCESS

CLIMATE RISK SCREENING

Preliminary, rapid assessment of the risks posed to a planned project as a result of climate change. Tools and methodologies used include Acclimatise, Aware; World Bank, Climate and Disaster Risk Screening Tool; International Institute for Sustainable Development, Community-Based Risk Screening Tool—Adaptation & Livelihoods (CRiSTAL).

PROJECT IMPACT ASSESSMENT

- Identify the climatic variables of interest for the project. These may include meteorological (e.g., temperature, precipitation); hydrologic (e.g., runoff volume, groundwater recharge, soil moisture); and other environmental (e.g., sea-level rise) variables. When their impacts are harmful, these variables are referred to as climate hazards.

ADAPTATION ASSESSMENT

- Establish adaptation objective.
- Identify adaptation options.
- Use a multi-criteria approach to appraise adaptation options (e.g., functional effectiveness, technical feasibility, affordability, stakeholder acceptability, etc.).

IMPLEMENTATION

- Establish implementation arrangements for selected adaptation measures (determine roles and responsibilities; identify needs for technical support and capacity building, etc.).

Sources: ADB 2017; USAID 2015a; GIZ 2014.

• Identify the changes in environmental conditions (or *system impacts*) likely to follow from changes in the above variables (e.g., reduced raw water quality, increased evapotranspiration, increased frequency of floods).	• Determine the vulnerability of different project components to changes in environmental conditions. Vulnerability is a function of th project's exposure, sensitivity, and adaptive capacity to a specific climate hazard.

• Conduct economic assessment of shortlisted adaptation options.	• Select adaptation strategy.	• Stakeholder engagement is critical to all of these steps.

This guidance note can help to inform these steps.

• Provide for ongoing monitoring and evaluation.

3. Project Climate Risk Management

This guidance aims to help project teams incorporate climate change considerations into project planning and design. It will support the broader climate risk management process, which begins with climate risk screening and concludes with project implementation. Figure 1 above briefly summarizes the climate risk management process.[2] Though the terminology and precise sequencing of steps vary, many comparable institutions, including multilateral development banks and bilateral development agencies, apply these steps in one form or another. See Appendix 1 for a glossary of key terms used in Figure 1 and throughout the note.

The first phase of the process is climate risk screening. IsDB plans to begin using Acclimatise Aware, a climate risk screening tool, for this phase.[3] It will use Aware at the early concept stage for all projects involving physical assets.

In addition to generating an overall climate risk ranking, Aware identifies key climate risk areas for the project, based on project category and location. If the initial climate risk screening using Aware indicates that a project has some level of climate risk, project impact and adaptation assessments follow. This guidance note is meant to support those phases of the climate risk management process.

Climate risk screening and project impact assessment together establish the climate change vulnerability context of a project. That context informs the adaptation assessment that follows, which aims to identify those measures best suited to reduce climate vulnerability, thereby establishing a direct link between specific project activities and the overall objective of reducing climate vulnerability. The sections that follow discuss project impact and adaptation assessments in greater detail.

4. Identifying Potential Impacts and Adaptation Options

As explained above, the Aware climate risk screening tool identifies the key climate risk areas based on the project's type and location. Project teams can use this information, along with expert judgment and other available climate data, to determine the climate hazards most likely to be relevant for a project. The World Bank's Climate Change Knowledge Portal[4] and The Nature Conservancy's Climate Wizard[5] are two examples of publicly available tools for identifying location-specific changes in climate conditions. From there, project teams can begin to evaluate the likely impacts and potential adaptation responses. This section provides tools to support this evaluation.

Identifying Potential Impacts

The decision trees below illustrate the process of identifying project vulnerabilities and adaptation options for projects involving water resources extraction and conveyance structures (Figure 2); water and wastewater treatment facilities (Figure 3); treated water storage and distribution networks (Figure 4); sewerage and piped collection networks (Figure 5); and small-scale sanitation systems (i.e., pit latrines and septic tanks) (Figure 6).

These decision trees primarily focus on the potential direct and indirect physical impacts of climate change. As described above, physical impacts could also lead to any number of nonphysical impacts, but because these tend to be highly context- and project-specific, they are not the focus below. Legal impacts, for example, will depend entirely on the legal and regulatory framework in the project country or the specific contractual arrangements underlying a project. That said, upon identifying potential physical project vulnerabilities, project teams should consider whether such vulnerabilities could have follow-on consequences for a particular project.

Finally, adaptation is highly context-specific, and the adaptation options identified will not be applicable or appropriate in all cases. For example, some may be too costly or technically infeasible in the project location. The steps described in Section 5 on appraising adaptation options will help project teams determine the appropriateness of different adaptation options for particular projects.


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FIGURE 2: DECISION TREE FOR WATER RESOURCES EXTR

CLIMATE HAZARD

Sea-level rise and storm surge

Increase in precipitation or increased frequency of extreme precipitation events

SYSTEM IMPACTS

Increased flood risk

Increased erosion, turbidity, and transport of pathogens and other pollutants

Saltwater intrusion

Increased algal bloom and pathogen levels; reduced dissolved oxygen

Less dilution of pollutant loads

PROJECT VULNERABILITIES

Flooding may cause damage to conveyance structures or disrupt operations directly or indirectly

Larger sediment loads may result in more rapid sedimentation of storage reservoirs

Reduced water quality at the point of extraction

ADAPTATION OPTIONS

✓Increase flood protection near conveyance structures using built and/or green infrastructure
✓Increase water capture and storage to avert flooding
✓Incorporate flood risk into infrastructure design (e.g., use water- and corrosion-resistant materials; design water intake to accommodate varying water levels, etc.)

✓Implement erosion control in the upstream watershed
✓Supplement storage capacity and/or remove deposited sediments to maintain existing capacity

ACTION AND CONVEYANCE STRUCTURES

Temperature increase

Decreasing precipitation and drought

Shorter, higher-intensity storms may reduce groundwater recharge

Increased evaporation and glacial melting; decreased seasonal snowpack

Increased water demand

Reduced streamflow and inflows to reservoirs and aquifers

Reduced reliability of supply; increased competition for limited supply

Diminished effectiveness of extraction; increased pumping costs

- ✓Relocate existing or planned extraction points
- ✓Diversify water supply options (e.g., recycling, rainwater harvesting, desalination)
- ✓Protect source water quality and reduce potential sources of contaminants within the catchment area (e.g., limit saltwater intrusion in coastal areas, implement green infrastructure to reduce runoff and associated pollutant loads, etc.)

- ✓Increase water capture and storage
- ✓Diversify water supply options (e.g., recycling, rainwater harvesting, desalination)
- ✓Implement water-use efficiency and demand management measures (pricing, metering, increase irrigation efficiency, etc.)

- ✓Modify extraction methods to accommodate lower flow or water levels

FIGURE 3: DECISION TREE FOR WATER AND WASTEWATER

CLIMATE HAZARD

Sea-level rise and storm surge

Increase in precipitation or increased frequency of extreme precipitation events

SYSTEM IMPACTS

Saltwater intrusion

Coastal flooding

Flooding (riverine floods/ flash floods, glacial lake outburst floods; urban flooding)

PROJECT VULNERABILITIES

WT: Additional treatment requirements, higher treatment costs, greater stress on treatment infrastructure, higher maintenance costs

Physical damage to treatment facilities; direct and indirect disruptions to operations (e.g., due to power outages)

ADAPTATION OPTIONS

- ✓*WT*: Increase treatment capabilities (e.g., additional pre-treatment steps)
- ✓*WT*: Develop an alternative raw water source
- ✓*WT*: Protect source water quality (i.e., limit saltwater intrusion by modifying pumping practice, establishing a physical or hydraulic barrier, natural or artificial aquifer recharge, etc.)

- ✓Increase flood protections near the facility, including built and/or green infrastructure
- ✓Incorporate projected flood risk into facility design (e.g., elevate critical components)
- ✓Re-locate existing or planned treatment facility to lower-risk area
- ✓Install emergency response equipment, like off-site pumps and generators
- ✓Integrate flood management procedures (e.g., forecasting and early warning systems) in operational planning

* *WT* = Water treatment facilities; *WWT* = Wastewater treatment facilities

TREATMENT FACILITIES

Temperature increase	Decreasing precipitation and drought

Reduced water quality in raw water source (WT) or in receiving waters (WWT)	Reduced streamflow and inflows to reservoirs and aquifers

Additional treatment requirements, higher treatment costs, greater stress on treatment infrastructure, higher maintenance costs	*WWT*: If water scarcity prompts conservation measures, wastewater streams will be more concentrated, increasing treatment requirements and cost

✓Increase treatment capabilities (e.g., additional pre-treatment steps) ✓Protect source or receiving water quality; reduce potential sources of conta minants within the catchment area, including through use of green infrastructure, like wetlands ✓*WT*: Develop an alternative raw water source ✓*WWT*: Develop systems to recycle water to decrease discharges to receiving waters	✓*WWT*: Adapt treatment processes to be able to handle increased target wastewater concentration

FIGURE 4: DECISION TREE FOR TREATED WATER STORAGE

CLIMATE HAZARD

Sea-level rise and storm surge

Increase in precipitation or increased frequency of extreme precipitation events

SYSTEM IMPACTS

Coastal inundation and storm surge flooding

Increased risk of flooding

Altered soil and rock conditions may increase ground movement or differential settlement

PROJECT VULNERABILITIES

Flooding could physically damage pipes, increasing maintenance costs and potentially causing leaks or disrupting service

Open-air storage tanks and basins exposed to potential contamination

Increased ground movement may damage buried assets, increasing maintenance costs and potentially causing leaks or disrupting service

ADAPTATION OPTIONS

- ✓Increase flood protection (including build and green infrastructure) near distribution networks
- ✓Relocate existing or planned distribution networks
- ✓Incorporate flood risk into distribution network design (e.g., use corrosion- or water-resistant materials, secure back-up power, etc.)
- ✓Conduct frequent monitoring and maintenance and employ leak detection technologies to ensure distribution system integrity

- ✓Cover or elevate storage facilities to protect from contamination

E AND DISTRIBUTION NETWORKS

Decreasing precipitation and drought

Temperature increase

Increased evaporation

Reduced water quality

Increased demand for water

Increased evaporative losses from treated water stored in open-air storage tanks and basins

Higher temperatures may lead to proliferation of certain pathogens within the distribution system

Need for additional storage capacity to meet growing demands

✓Design to account for changes in the soil moisture conditions and movement (e.g., use shorter lengths of pipe)
✓Conduct frequent monitoring and maintenance and employ leak detection technologies to ensure distribution system integrity

✓Increase shading, cover storage facilities, or use chemical water evaporation retarders to minimize evaporation

✓Design distribution systems to reduce residence times within pipes
✓Coat exposed pipes with white paint or reflective materials

✓Increase water storage capacity

FIGURE 5: DECISION TREE FOR SEWERAGE AND PIPED CO

CLIMATE HAZARD

Sea-level rise and storm surge

Increase in precipitation or increased frequency of extreme precipitation events

SYSTEM IMPACTS

Coastal inundation and storm surge flooding

More frequent and intense flooding

PROJECT VULNERABILITIES

Saline water in collection and conveyance systems could reduce capacity, increase risk of untreated sewage discharge, and degrade pipes

Physical damage to sewerage

Service disruption due to power outage

ADAPTATION OPTIONS

✓Relocate sewerage networks
✓Increase flood protection (including build and green infrastructure) near sewerage networks
✓Install emergency response equipment (e.g., redundant pumps and generators)
✓Incorporate flood management prodecures (e.g., forecasting and early warning) into operations

✓Minimize pumping requirements
✓Install emergency response equipment (e.g., redundant pumps and generators)
✓Elevate or protect existing electrical equipment from flooding

LLECTION NETWORKS

Decreasing precipitation and drought

Altered soil and rock conditions may increase ground movement or differential settlement

Reduced water availability

Combined sewer overflow

Increased ground movement may damage buried assets, increasing maintenance costs and potentially causing leaks and disrupting service

If water conservation measures cause low flows, it may lead to great deposition of solids and increased incidence of blockages

✓Separate stormwater and sanitary sewer systems
✓Construct conveyance and storage system to intercept and store combined sewer overflow water
✓Expand green or nature-based stormwater infrastructure
✓Increase sewerage capacity to reflect increase in precipitation and extreme rainfall events. Incorporate precautionary allowance in design

✓Design to account for changes in soil moisture conditions and movement (e.g., use shorter lengths of pipe)
✓Conduct frequent monitoring and maintenance to detect breakages

✓Modify sewer design to cope with low or intermittent flows
✓Adapt inspection and maintenance program to detect blockages and increase flushing

FIGURE 6: DECISION TREE FOR SMALL-SCALE SANITATION

CLIMATE HAZARD

Sea-level rise and storm surge

Increase in precipitation or increased frequency of extreme precipitation events

SYSTEM IMPACTS

Sea-level rise and storm surge flooding

Rising water table

PROJECT VULNERABILITIES

Rising water tables could expose underground structures to ground movements and flotation, which could cause structural damage (e.g., pit collapse) and inundation

Septic tanks and pit latrines may be flooded or filled with silt, which could cause structural damage and result in environmental contamination of surrounding areas

ADAPTATION OPTIONS

✓Improved pit latrines help avoid collapse from erosion or inundation
✓Additional planting and soil compaction to limit ground movements and erosion

Sources (Figures 2-6): ADB 2012; FAO 2016; FAO 2011; FAO 2017; Fanzo et al. 2018; IFPRI 2017; Lipper et al. 2018; Rojas-Downing et al. 2017; Thornton et al. 2015; Cochraine et al. 2009; IFAD 2014; Beuno and Soto 2017; Brown et al. 2015; Stathers et al. 2013; Khan et al. 2014; Tran et al. 2014; Sabbag 2013; Barnett et al. 2013; USAID 2013a; World Bank 2015; World Bank 2009.

N SYSTEMS

Decreasing precipitation and drought

Increased risk of flooding

Reduced streamflow and inflows to reservoirs and aquifers

Reduced reliability of systems that depend on water; less water available for flushing and cleaning pit latrines and septic tanks

✓In high-risk areas, consider low-cost temporary sanitation facilities that be easily moved and rebuild
✓Risk-based siting: site systems in lower-risk areas and away from water supply sources
✓Increase flood protection and erosion control measures near facilities
✓Incorporate flood risk into facility design (e.g., reduce depth and volume of pit/tank; install sealed covers; empty pit/tank more frequently; line pits; install non0return valves on tanks; elevate latrines)

✓Gray water recycling strategies or water reclamation could be used to reduce sanitation system's dependence on fresh water
✓Consider lower water-use approaches for flushing and cleaning (e.g., low-flush toilets)

Identifying Adaptation Options

Once a project team determines potential project vulnerabilities, it can proceed to identifying possible adaptation solutions. An important preliminary step is defining the objective of adaptation. In setting objectives, project teams should consider what vulnerabilities they seek to address and what their desired outcomes are. Seeking input from relevant stakeholders for this stage and throughout the process will improve the likelihood that the ultimate adaptation decisions are deemed successful (UK Climate Impacts Programme 2007).

Ideally, the objective would include specific timelines and measurable thresholds for what would and would not be considered successful adaptation. For example, the objective could be to achieve a certain level of flood protection (e.g., protect facility from physical damage by 100-year flood event or ensure facility remains fully operational during 50-year flood event) or a certain degree of resilience (e.g., ensure facility can resume operations within five days of a 100-year flood event).

Once the team defines its adaptation objectives, it should strive to compile a wide range of measures to meet those objectives. The above decision trees offer an initial, nonexhaustive list of potential adaptation options for addressing particular climate impacts. Because this guidance applies to projects involving physical assets, many of the options identified are structural or physical adaptation options. Such options are often referred to as “hard” adaptation options. They involve on-the-ground physical infrastructure and technical equipment, like additional water storage capacity or new water treatment facilities. Structural adaptation options also include a variety of ecosystem- or nature-based adaptation measures (Noble et al. 2014). There are also a variety of nonstructural (or “soft”) adaptation options. See Box 1 for more detail on soft adaptation options.

Box 1 | Soft Adaptation Options

Soft adaptation encompasses management, operational, or policy changes, as well as capacity-building and knowledge-management activities. Many soft adaptation measures are not specific to a particular subsector or category of project and, instead, are sensible across a wide range of projects. For example, improved data collection and forecasting capabilities, climate information services, and early warning systems may be critical to the success of projects in any of the subsectors this note covers.

Other examples of soft adaptation **measures** include **policy measures** aimed at reducing overall demand for water or incentivizing water conservation; **capacity-building efforts**, like training on the use of new technologies; and **institutional changes** to improve water governance, such as the establishment of community-based water users’ groups.

Building resilience often requires a combination of hard and soft adaptation measures, as well as engineered and nature-based infrastructure options, because the underlying causes of vulnerability are often diverse (UNEP 2017). Moreover, the varied and complex ways water systems interact with other sectors and systems means that adopting a narrow, sector-based approach to adaptation may not be sufficient; instead, a holistic, integrated approach is needed (UNEP 2017; ADB 2017). As such, in identifying adaptation options, project teams should seek to develop a wide range of options. Consulting with a variety of stakeholders (including community and nongovernmental organizations, environmental specialists, engineers, and others) can help to identify a comprehensive list of adaptation options (ADB 2017).

Finally, in identifying adaptation options, project teams should remember that adaptation measures will ideally be aligned with existing country or sector resilience plans.

5. Appraising Adaptation Options

A variety of approaches are available for evaluating and prioritizing among adaptation options.[6] One such approach, described below, is to use multi-criteria analysis to identify a short list of preferred adaptation options, followed by a more detailed, quantitative assessment of those options.[7]

At the outset, assessing the performance of different adaptation measures, whether in qualitative or quantitative terms, requires an understanding of future climate conditions. The adaptation options identified in the above decision trees vary widely in cost. The level of investment in adaptation that is economically justified will depend on the severity of potential impacts within the relevant time horizon. Accordingly, project teams must develop climate change scenarios representing plausible future states (ADB 2017). They first identify the climatic and hydrological variables most relevant to project design. They can then use climate model projections, analysis of historic data, available studies, and expert judgment to develop assumptions about how those variables are likely to change over the project's life span (ADB 2017). The World Bank's Climate Change Knowledge Portal, mentioned above, includes location-specific climate data and references to a variety of other climate data sources, and the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Centre[8] provides general guidance on the use of scenarios and data in adaptation assessments. Additional analysis, including simulation modeling, may be required to determine how changes in primary climatic and hydrological variables can lead to more complex phenomena, such as drought or flooding (ADB 2017). Finally, project teams can judge project performance in the context of probable future conditions.

Although climate projections are an imperfect representation of reality, they allow project teams to explore how the future may unfold and how the project will perform under different conditions. That said, uncertainty about future climate conditions creates important methodological challenges for adaptation decision-making, so this section concludes with a brief discussion of the importance of incorporating uncertainty into appraisal of adaptation options.

Multi-Criteria Analysis

Multi-criteria analysis allows for a qualitative and comparative assessment of different adaptation options. It is often used to assess factors that are not easily quantifiable in monetary terms or during preliminary stages when the precise cost implications of various options have yet to be developed (USAID 2015a). Multi-criteria analysis should be conducted in a participatory manner that seeks input from the external stakeholders likely to be affected by the project and any potential adaptation measures (Trevor et al. 2011).

The project team would first identify the appropriate criteria for the given project, such as the following (USAID 2015a; European Commission 2013; Weiland and Troltzsch 2015):

- *Functional effectiveness*
  - Does the adaptation measure accomplish the desired outcome?
  - Does it do so within an acceptable timeframe?
- *Technical feasibility*
  - Is the measure technically feasible in the project location?
- *Affordability*
  - Are the upfront costs of the measure affordable?
  - Are operations and maintenance costs of the measure affordable?
- *Stakeholder acceptability*
  - Does the measure have cultural, economic, or environmental effects that could impact stakeholder or community acceptance?
- *Ease of implementation*
  - Are there factors (e.g., those related to human capital, availability of materials, or existing technical skills) that may impede implementation?
- *Flexibility/robustness*
  - How effective will the measure be in the face of uncertain future conditions?
- *Cobenefits*
  - Does the measure support other climate-related (e.g., carbon sequestration) or development objectives (e.g., economic security, private sector development, institutional strengthening)?

The project team would then agree on a scale or metric for each criterion. In some cases, quantitative metrics, like cost, may be available. In others, qualitative metrics can be translated into a numerical form (e.g., on a 1 to 5 scale) (USAID 2013; Van Ierland et al. 2013). Project teams could also attach different weights to different criteria to reflect relative importance (USAID 2013).

Next, the project team would score projects incorporating the different adaptation alternatives against each of the criteria. As described above, the performance of different options will depend on projected climate conditions. For example, evaluating the functional effectiveness of a planned shoreline protection measure would require sea-level–rise projections for the lifetime of the project.

Finally, the project team would compare the weight-adjusted scores of the various alternatives (UNFCCC 2011). The project team could use the outcome to produce a short list of preferred options that perform best against the selected criteria.

Detailed Economic Assessment

The remaining options can then be evaluated in greater detail using a quantitative economic assessment. Two possible techniques for economic assessment of adaptation options are cost-benefit analysis and cost-effectiveness analysis (GIZ 2013; UNFCCC 2011).

- Cost-benefit analysis

Cost-benefit analysis (CBA) involves quantifying (in present-value terms) and comparing the costs and benefits of an adaptation investment to determine its likely efficiency (UNFCCC 2011). CBA is generally the preferred technique, so long as all costs and benefits of adaptation can be expressed in monetary terms (GIZ 2013). Adaptation costs include direct costs, like initial investment and operating costs, as well as any indirect costs, like transitional costs or social welfare losses (UNFCCC 2011).

Adaptation benefits include benefits accrued and losses avoided as a result of an adaptation measure (IPCC 2007). As such, adaptation benefits are assessed relative to a project baseline (i.e., the project without adaptation).[9] The appropriate project baseline and net benefits of different adaptation options relative to that baseline are ultimately dependent on future climate conditions. Project teams first assess the costs and benefits of the project baseline under projected climate conditions. Where multiple future scenarios are plausible, there would be multiple baselines (European Commission 2013). They then assess the net benefits of various adaptation alternatives relative to the baseline(s).

Adaptation projects often involve impacts on things like public health, environmental quality, or cultural heritage. These sorts of nonmarket costs and benefits are difficult to quantify but should not be excluded from any economic analysis conducted. Instead, techniques like contingent valuation should be used to estimate nonmarket costs and benefits, where possible (UNFCCC 2011). Contingent valuation uses the stated preferences of impacted individuals to estimate the economic value of nonmarket goods, like ecosystem services. For example, contingent valuation could be used to estimate the monetary value of an artificial wetland's benefit to water quality by asking impacted individuals how much they would be willing to pay for an equivalent water quality improvement.

Having quantified all costs and benefits, project teams discount them to present value and aggregate them to compute the net present value (NPV) of each alternative. The NPVs of different adaptation options can then be compared to identify the most suitable option or options.

- Cost-effectiveness analysis

Cost-effectiveness analysis identifies the least cost option or set of options for achieving adaptation objectives (UNFCCC 2011). It can be applied when adaptation benefits are difficult to quantify and express in monetary terms.[10] Cost-effectiveness analysis may also be appropriate in situations where the issue is not whether to adopt adaptation measures but rather how to achieve a certain level of adaptation in the most cost-effective way.

Like cost-benefit analysis, this technique requires planners to quantify (in monetary terms) the various costs of adaptation options. Project teams quantify all costs, discount them to present value, and aggregate them. Rather than quantifying project benefits in monetary terms, project teams quantify them in physical terms (Watkiss et al. 2013). The unit of measurement depends on the adaptation objective. For example, for a project seeking to ensure reliable access to freshwater resources, project teams might calculate the number of households with access to quality freshwater throughout the year. Project teams can then compare different options in terms of their cost effectiveness, measured as cost per unit of benefit delivered.

Incorporating Uncertainty into Adaptation Decision-Making

Traditional economic assessment techniques, like those described above, assume an ability to confidently predict future climate conditions or at least attach probabilities to possible future scenarios. In reality, there is considerable uncertainty about the speed, direction, and magnitude of future climate changes in many regions, particularly on the scale relevant to a specific project (Ranger et al. 2013). Uncertainty has countless sources, including uncertainty about emissions trajectory and uncertainty stemming from climate models and efforts to downscale model projections to regional or local levels, particularly in areas with complex topography (ADB 2015). Questions surrounding future socioeconomic development, population growth, and other nonclimate stressors only add to this uncertainty.

The presence of uncertainty does not invalidate techniques like cost-benefit or cost-effectiveness analysis, but decision-makers must take uncertainty into account, and doing so might require them to alter their decision-making approach. Traditional decision-making processes predict future conditions and design projects that perform optimally under those conditions. Alternatively, if multiple future states are possible, probabilities of occurrence can be attached to the different future states, and projects can then be designed to maximize expected NPV. As uncertainty increases, however, this sort of "predict-then-act" approach becomes less applicable (Hallegatte et al. 2012).

Rather than using economic assessments to identify the optimal solution for a single, best-guess projection, decision-making under uncertainty is focused on increasing the robustness of a project—that is, the project's ability to fulfill its intended objective across a range of plausible futures (Hallegatte et al. 2012). Certain simple strategies exist for adding robustness to traditional decision-making processes (Ray and Brown 2015).

- *Incorporating safety margins into adaptation planning* (Hallegatte et al. 2012). Where the marginal cost is low, incorporating safety margins into adaptation planning is a practical way to deal with uncertainty over future conditions. Increasing the height of a planned sea wall to hedge against the worst-case scenario is an example of a safety margin strategy (Ray and Brown 2015). Factors such as incremental cost, consequences of system failure, and life span of the asset would all inform the size of any safety margin incorporated into a project (Ray and Brown 2015). This sort of conservative approach is especially important when the adaptation measure under consideration is irreversible (Hallegatte et al. 2012).
- *Stress testing the outcomes of economic assessments using sensitivity analysis* (Penning-Rowsell et al. 2013). Sensitivity analysis tests how changes in key parameters impact project performance (Ray and Brown 2015; Edmund Penning-Rowsell et al. 2013). In particular, project teams can test the sensitivity of the project's NPV to changes in uncertain variables, such as rainfall projections (ADB 2015). While a practical tool for exploring the possible impacts of uncertainty on project performance, sensitivity analysis is subjective, relying on judgment rather than empirical evidence, and as such, is of limited usefulness in the presence of substantial uncertainty (ADB 2015).
- *Identifying no-regret and low-regret measures to implement in the near term that will yield benefits regardless of the nature and extent of climate change.* No-regret and low-regret options are beneficial even if climate projections end up being incorrect (Hallegatte et al. 2012). A common example is limiting water pipe leakages (Hallegatte et al. 2012). One way to identify no- or low-regret strategies is to recognize present problems that can be cost-effectively addressed using measures that also reduce longer-term climate vulnerabilities, and, in fact, addressing current adaptation deficits is often an effective near-term, no-regrets strategy (Hallegatte et al. 2012).

Decision-making under uncertainty also emphasizes flexibility. Because uncertainty will decrease over time, flexible approaches that can be modified or reversed as more information becomes available are preferable (UNFCCC 2011). This includes both structural and planning flexibility. Structural flexibility involves engineering features so that infrastructure can be enhanced in the future if climate impacts are high. Planning flexibility refers to decision-making that is intentionally iterative and designed to be adjusted over time (UNFCCC 2011).

In situations of greater uncertainty (situations involving investments in long-lived infrastructure, for instance), project teams may need to turn to new, more complex methodologies specifically designed to support decision-making in the context of uncertainty. These include robust decision-making (Lempert et al. 2006; Lempert et al. 2013; Hallegatte et al. 2012; Swart et al. 2013), real options analysis (Swart et al. 2013; Hallegatte et al. 2012; Linquiti and Vonortas 2012), and portfolio analysis (Swart et al. 2013). The details of these methodologies are beyond the scope of this guidance, but briefly, robust decision-making uses sophisticated analytical tools to identify adaptation strategies that perform well over a wide range of possible future climates (Ray and Brown 2015). Real options analysis extends more traditional cost-benefit analysis to explicitly include valuation of the flexibility or adaptability of design options; it can be useful in deciding whether to invest in adaptation immediately or to delay investment (Hallegatte et al. 2012). Portfolio analysis guides the selection of a set of adaptation options (rather than a single option) that together perform well across a range of plausible future climates (Hunt and Watkiss 2013).

6. Case Studies

The following case studies provide illustrative examples of how the above processes might look in practice. The first, involving an Asian Development Bank (ADB) project in Bangladesh, typifies many of the processes described above. It provides an example of a project team pinpointing the relevant climate hazards, deducing potential project vulnerabilities, defining adaptation objectives, and identifying adaptation options. The second involves an African Development Bank (AfDB) sanitation project in rural Sierra Leone. It describes a situation in which a mix of hard and soft adaptation solutions was necessary for the success and sustainability of a project.

Climate-Proofing Water Supply and Sanitation Infrastructure in Bangladesh

An ADB project is currently underway to expand water supply and sanitation systems in eight towns across Bangladesh's coast (ADB 2014b). Project activities include installing or upgrading water pipes, establishing new water supply service connections, and constructing new community latrines, among others. Bangladesh's low-lying coastal areas, including the eight towns that are the focus of ADB's project, are highly vulnerable to tropical cyclones, storm surge flooding, and sea-level rise (ADB 2014b). Given that these conditions potentially threaten water supply and sanitation, ADB conducted a detailed climate risk assessment for the project (ADB 2014a).

The climate risk assessment used General Circulation Models and dynamically downscaled data from a Regional Climate Model to generate climate scenarios based on high and medium emission pathways for the 2030s and 2050s time horizons (ADB 2013). The assessment identified (1) increasing frequency and intensity of rainfall-induced flooding and tropical cyclones; and (2) sea-level rise as key climate hazards (ADB 2014a). It used hydrodynamic and urban drainage models to evaluate the potential project vulnerabilities associated with those hazards. While acknowledging "cascading uncertainty beginning from the climate change projections to hydrodynamic and urban flooding models," the assessment found that flooding and tropical cyclones could physically damage or impair the operations of water supply and sanitation structures, and saltwater intrusion associated with sea-level rise could degrade critical surface- and groundwater sources, thereby threatening water security (ADB 2013).

Given these vulnerabilities, the project team conducted an adaptation assessment. In addition to the overarching goal of increasing the resilience of water supply and sanitation in coastal towns, the project team also identified several measurable objectives for adaptation. For water supply, the project aims to increase the percentage of drinking water supply systems compliant with government water standards throughout the year to 70 percent (from the 2013 baseline of 40 percent) in project towns by 2020. For sanitation, it seeks to extend access to climate-resilient public sanitation facilities (including public/community latrines and septage management schemes) to an additional 12,500 households in project towns by 2020 (ADB 2014b).

Having defined its adaptation objectives, the project team then identified potential adaptation options. Adaptation options for water supply investments include the following:

- Exploring alternative nonsaline sources of water (including rainwater harvesting)
- Siting surface water intakes based on salinity tests and projected sea-level rise
- Modifying well casing of production tube wells to protect against flooding and storm surges
- Providing back-up power to keep water supply systems operational during storms
- Providing flood protection measures (including embankments) around water treatment plants
- Using high-density polyethylene pipes in place of polyvinyl chloride (PVC) pipes to increase durability and reduce water losses (ADB 2014a, 2018)

Options for sanitation investments:

- Constructing septic tanks and superstructures for public toilets and community latrines above the 2050 high flood level to protect against inundation
- Positioning pits of latrines above flood level (ADB 2014a, 2018)

Different measures are being deployed in the different towns based on location-specific vulnerabilities and priorities, but all infrastructure will be designed based on climate projections for the year 2050 (including projected precipitation, temperature, tide and/or floods, and surge levels) (ADB 2014a, 2014b, 2018). In total, the project will install or upgrade 194 kilometers (km) of water pipes, establish 12,360 new service connections in poor areas, construct 51 new community latrines, and implement 5 new septage management schemes (ADB 2014a, 2014b, 2018).

Coupling Hard and Soft Adaptation Technologies for Sanitation in Sierra Leone

A decade of conflict destroyed much of Sierra Leone's sanitation infrastructure. The civil war ended in 2002, but in 2013, only 7 percent of the rural population had access to improved sanitation facilities (AfDB 2013b). Addressing this deficit is critical to climate adaptation in Sierra Leone, as unsustainable septage management threatens water quality and worsens environmental degradation, and climate change is likely to exacerbate those risks. Climate projections for Sierra Leone include rising temperatures, increasingly frequent extreme rainfall events, and a heightened risk of flooding (DFID 2013). Additionally, low-lying coastal areas are vulnerable to sea-level rise, which could exacerbate risk of flooding and coastal erosion (ODI 2014).

A project is currently underway to increase access to sanitation services in five rural districts in Sierra Leone. The project is constructing 170 new sanitation facilities, including ventilated pit latrines and organic refuse-based biogas plants (AfDB 2013a; Global Environment Facility 2012). Recognizing that heavy rainfall and flooding will overwhelm and potentially damage infrastructure not built to cope with such conditions, the project is promoting flood-resilient technologies, like ecological sanitation ("EcoSan") toilets. Ecosan toilets remain accessible during extreme rainfall and are less likely to contaminate nearby water resources because they are dry toilets, constructed on raised platforms. The project is also focused on improving sanitation facility siting to reduce the risk of contamination of surface and groundwater resources (AfDB 2013a).

The project is expected to increase access to improved sanitation from 7 to 13 percent in rural Sierra Leone and to extend access to 91,000 school children (AfDB 2013b). While these gains are important, scaling them up will be a challenge because hydro-meteorological data for Sierra Leone are extremely limited. Recognizing this limitation, the project also includes plans to develop the country's hydrogeological map and install surface and groundwater monitoring stations (AfDB 2013a). Better data would support the improved climate projections and hydrological modeling needed to assess adaptation needs and design adaptation solutions. The project also includes capacity-development activities, like training for water, sanitation, and hygiene (WASH) professionals on climate-resilient WASH practices (Global Environment Facility 2016). These soft adaptation measures are critical to scaling up adaptation in the water sector.

Appendix I: Glossary

Adaptation. The process of adjustment to actual or expected climate change and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate change and its effects.

Adaptive capacity. The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

Climate change. Climate change refers to a change in the state of the climate that can be identified (for example, via statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use.

Exposure. The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Hazard. The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term 'hazard' usually refers to climate-related physical events or trends or their physical impacts.

Impacts. The effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes.

Projection. A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.

Resilience. The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

Risk. The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard. In this report, the term "risk" is used primarily to refer to the risks of climate-change impacts.

Risk management. Plans, actions, or policies to reduce the likelihood and/or consequences of risks or to respond to consequences.

Sensitivity. The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

Uncertainty. A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior.

Vulnerability. The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.[11]

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Endnotes

1. For additional information on IsDB's operations, see https://www.isdb.org/where-we-work.
2. See Appendix 1 for a glossary of key terms used in Figure 1 and throughout the note.
3. For more information on the Acclimatise Aware tool, see http://www.acclimatise.uk.com/analytics/applications/.
4. For more information on the World Bank Climate Change Knowledge Portal, see http://sdwebx.worldbank.org/climateportal/index.cfm.
5. For more information on The Nature Conservancy's Climate Wizard, see http://www.climatewizard.org/.
6. See e.g., GIZ, (2014); European Commission (2013); USAID (2015a).
7. The proposed approach draws on European Commission (2013) and USAID (2015a).
8. For more information on the IPCC Data Distribution Centre, see http://www.ipcc-data.org/index.html.
9. ECONADAPT Toolbox: Cost-Benefit Analysis, https://econadapt-toolbox.eu/node/12.
10. ECONADAPT Toolbox: Cost-Effectiveness Analysis, https://econadapt-toolbox.eu/cost-effectiveness-analysis.
11. All definitions in Appendix 1 taken from IPCC 2014, 1–32.