

CLIMATE CHANGE ADAPTATION TECHNOLOGIES FOR WATER

A PRACTITIONER'S GUIDE
TO ADAPTATION
TECHNOLOGIES FOR
INCREASED WATER
SECTOR RESILIENCE

UN Environment-DHI Centre
on Water and Environment





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EXECUTIVE SUMMARY

Water is central to the sustainable functioning of the ecosystems on which our socioeconomic activities depend. For example, it is essential for agricultural production and energy generation, as well as for industrial production and domestic use. Beyond the provision of water as a resource, aquatic ecosystems also provide other indispensable services, including water purification, flood mitigation, wildlife habitats and recreational possibilities, to name but a few.

It is generally accepted that one of the climate change's main impacts is on the hydrological cycle, with the big picture being that wet areas of the world are generally getting wetter, and dry are getting drier. In addition to this, we are experiencing more severe weather and climate change effects, such as floods, sea level rise and storm surges. Rising temperatures negatively affect the quality and availability of water resources, the impacts of which are particularly felt by poorer and more vulnerable groups. Climate change models predict that by the end of this century, a significantly higher number of people will be exposed to water-related challenges, including floods and droughts (IPCC 2014), putting millions of lives and substantial economic assets at risk.

It is already evident that climate change is affecting hydrological fluxes at all scales. Strengthening the ability to adapt to these changes in a way that mitigates hazards and risks to humans and the environment is vital for sustainable development and the survival of communities. We already have the capability, however, to prepare for and avoid some of these hazards, through a combination of selected technologies and technical expertise, though those looking for appropriate solutions inevitably face the difficult task of identifying and evaluating a bewildering range of options.

This guide aims to help address this challenge by providing the missing identification and evaluation assistance that those looking for adaptation solutions initially face. More specifically, it focuses on adaptation technologies for building resilience to climate change induced hazards in the water sector. It provides a simple and comprehensive overview of specific water technologies and techniques that address challenges resulting from climate change and help to build

adaptive capacity. The cornerstone of this guide is the water climate change adaptation technology taxonomy developed for the purposes of this guide (Figure 1), systematizing the most pressing climate change challenges in water sector, and their corresponding water adaptation technologies.

The immediate focus of this guide is on adaptation technologies relevant to ensuring sustainable supplies of clean water and mitigation of water-related disasters. Although it focuses primarily on mitigating the immediate impacts on water resources management, implementing these technologies could have considerable impacts on a number of related sectors, as well as development goals¹.

As presented in Figure 1, this guide systematizes water adaptation technologies based on the immediate water challenges they address. This guide takes six current climate-related water challenges as an entry point to identifying relevant adaptation responses, followed by identification of the specific water adaptation technologies relevant for each response.

A total of 102 water adaptation technologies are included in this guide. Further to introduction of the adaptation technologies, several approaches to selection and prioritization of the adaptation technologies are discussed in chapter 5.

¹ Seen in the context of the global Sustainable Development Goals, investment in water adaptation technologies may have a vast positive impacts on targets within Goals 6, 13, 14, 15 just to name a few. More on Sustainable Development Goals and the Global Agenda for 2030 at: <https://sustainabledevelopment.un.org/>

FIGURE 1

Climate change adaptation and water – overview of challenges and responses.



1. INTRODUCTION

1.1 CLIMATE CHANGE IMPACTS AND WATER RESOURCES

Water is pivotal to the sustainable functioning of ecosystems and human socioeconomic activities. As a resource, it enables agriculture and food production, energy generation, domestic use and industrial production. Aquatic ecosystems in turn provide ecosystem services that are essential for humans and nature. These services include water purification, flood mitigation, wildlife habitats, nutrient cycling, recreational possibilities, spiritual values and many more. Continued delivery of these ecosystem services is essential to everyone. The poor are particularly vulnerable to rapid changes in service delivery and climate change impacts such as floods and droughts as they often rely on nature for their livelihoods.

The health of aquatic ecosystems in many parts of the world has been significantly impacted by human activity, where drivers such as deforestation, land conversion and agricultural and industrial pollution have compromised delivery of water services. The continued availability of clean and sufficient water for people and nature is threatened by climate change.

The findings of the Fifth IPCC Assessment report (IPCC 2013) (IPCC 2014) confirm the impacts of climate change on the global water cycle. Modelled results predict higher variability and contrast between wet and dry regions, as well as wet and dry seasons. While there are regional differences and an inherent uncertainty with the modelled scenarios, large-scale trends based on future emissions scenarios have been identified. Amongst others, these include an increase in annual mean precipitation at high latitudes and the equatorial Pacific Ocean. The frequency and intensity of extreme precipitation events in wet tropical regions is also expected to increase.

On the other hand, a decrease in rainfall is expected in many mid-latitude and most subtropical dry regions, where projections show significant reductions in renewable surface water and groundwater resources (IPCC 2014).

The frequency and severity of flood events is projected to increase globally, and especially in parts of South, Southeast, and Northeast Asia, tropical Africa, and South America. Modelled scenarios also indicate that the frequency of meteorological droughts (less rainfall) and agricultural droughts (less soil moisture) will

increase in dry regions (IPCC 2014). Overall, climate change models predict that by the end of this century, a significantly higher number of people will be exposed to both floods and droughts (IPCC 2014), putting lives and economic assets at risk. Many of these events are taking place, and can be observed today.

Coastal areas (particularly low-lying communities) are already facing the impending threat of sea level rise as a result of ocean thermal expansion and glacier mass loss in a warming climate. The immediate impacts include submergence, coastal flooding and coastal erosion, with additional risks that may result from changes in storm patterns and associated storm surges (IPCC 2014).

The impacts of climate change on water are singularly relevant, but also need to be examined in the context of global population growth. For example, even with minimal or moderate decreases in water availability, the impacts can be magnified in regions with high population density and rapid population growth, leading to resource degradation with trickle down effects across a number of sectors.

The following chapter further discusses ways in which the changing global hydrological cycle will affect human socioeconomic activities and its direct impacts on various water resources and water ecosystem uses.

1.2 CLIMATE-RELATED VULNERABILITIES IN WATER USE AND MANAGEMENT

The effects of climate change on a number of important water uses and user groups are outlined below. This list is not exhaustive, but serves to highlight the magnitude of impacts on various water uses, and thus the impact of investment in water adaptation technologies across sectors, and vice versa - the lack of it.

Water supplies

Nearly all emissions scenarios predict decreased availability of renewable surface and groundwater resources for a significant share of global population. The IPCC findings show that each degree of global warming is projected to decrease the availability of renewable water resources by at least 20%, for additional 7% of the global population. The percentage of global population living in river basins with new

or exacerbated water scarcity is also projected to increase, to as high as 13% (at 5 degrees Celsius) (IPCC 2014). A lack of adequate adaptation responses will lead to additional pressures on drinking water delivery systems, which are already under stress due to population growth and lack of investment in the ageing water infrastructure. This will not only necessitate finding alternative water sources for urban and rural drinking water supplies, but also increase the potential for conflict where local resources are scarce. Lack of an adequate water supply is also linked to vital health issues such as sanitation and water borne diseases.

In addition to pollution originating from point and non-point sources such as untreated industrial effluents and agricultural fertilizers, increased pressures on water resources in areas facing climate change-induced water scarcity can be a significant driver of water quality degradation. Decrease in rainfall, coupled with increasing withdrawals (due to growing population and socioeconomic activity), reduce the diluting capacity of water, thus increasing risks of eutrophication and de-oxygenation. Research (Xia, et al. 2016) also points to an acceleration in the eutrophication in lakes, rivers and reservoirs, driven by increasing temperatures. Associated increases in algae producing toxins, outbreaks of algal blooms and formation of hypoxic environments affect water quality and the general health of ecosystems.

A warmer climate also fosters growth of viruses and bacteria, as well as invasive species, which in turn affects the quality of available supply. The changing climate is also expected to contribute to increasing sediment and nutrient loads due to the increased intensity of rainfall events (Xia, et al. 2016). In urban areas, heavy rainfall and flash floods create the risk of sewer overflows, and consequently water contamination.

Water for environment

In an environment where freshwater species are already facing faster rates of deterioration than those in all other ecosystems (WWF 2014), the changing climate is causing shifts in seasonal stream flow patterns in many rivers. The seasonal occurrence of low and high flows form a delicate balance in water ecosystems in many parts of the world, where key species rely on these changes in river flows and seasonal inundation for migration, food, fish breeding, etc. Changes in these patterns (in addition to those created by human activity) can have detrimental effects on habitats, altering the delivery of essential ecosystem services for species survival, including humans.

Ensuring that sufficient water remains in perennial rivers and streams is essential for sustaining environmental flows and the health of ecosystems.

However, when human pressures on limited resources increase, water that is essential for environmental services is often compromised, leading to species extinction and ecosystem degradation. Many ecosystem services that humans heavily rely upon become degraded as well – including supply of sufficient and clean water, flood protection, groundwater recharge, fish production, to name a few.

Agriculture

The primary user of freshwater globally is agriculture, which relies on rainfall and irrigation for continuous supplies. Agricultural withdrawals currently account for more than 70% of global freshwater use (Wetlands International 2010). Agricultural water use includes direct needs for food and livestock, as well as soil water supply. Increasing evaporation/evapotranspiration rates in some regions will significantly increase irrigation water demands (IPCC 2014). Rainfed agriculture, the lifeline of farmers in many developing countries, is particularly vulnerable to increased precipitation variability, and the yields from rainfed agriculture are expected to decrease by up to 50% in some countries by as early as 2020 (Wetlands International 2010). Further risks to agriculture and yields stem from increasing frequencies of extreme weather events. Extreme weather events in the form of floods and droughts are already causing major disruptions and losses in agricultural production systems, particularly where no adaptation solutions are in place to mitigate the risks.

In addition, millions of people depend on seasonal snow and glacier-melt waters for their agriculture water supply. It is well documented that glaciers are retreating at a rapid pace, presenting risks of floods in the short term, and water scarcity in long term.

Industrial and energy production

Energy and industrial sectors are also major water users and have particular significance for socioeconomic development. Disruptions in water supply can cause interruption of crucial services such as energy production and medical services.

Large amounts of water are necessary for energy production, including hydroelectric power plants and the cooling of thermal power plants, as well as irrigation of energy crops for biofuel production. Climate change impacts that affect energy production include not only reduction of overall water availability, but also changes in the seasonal flows of streams that many hydroelectric plants rely on for power generation. Hydropower plant reservoirs will also be affected by increased evaporation from reservoirs and changes in sediment fluxes (IPCC 2014). Additional impacts

the efficiency and demand for cooling technologies in thermal power plants.

Industrial production facilities will be affected in regions with increasing water scarcity (annual or seasonal), with the potential to drive up costs of production or eliminate the facilities altogether. Changes in water quality may also affect the energy and investment needs for processes that require particularly high quality water inputs (e.g. the pharmaceutical industry).

Increased incidence of extreme events, such as floods, can cause disturbances and significant damage to all infrastructures, including energy and industrial production facilities. Thus, special attention needs to be given to adaptation responses that can protect strategic infrastructure.

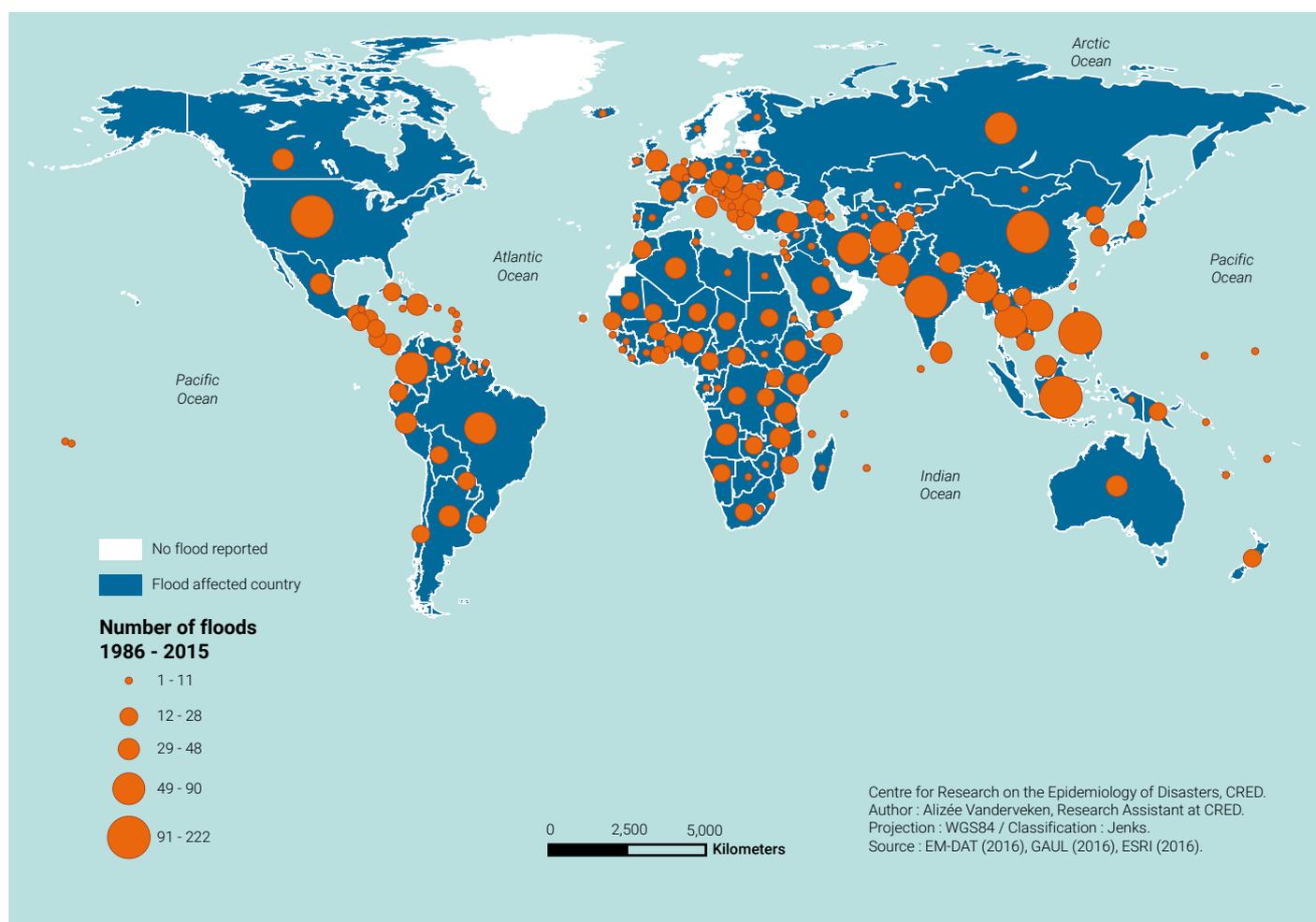
Cross-cutting challenge: extreme weather events

A crosscutting challenge relevant to all water sectors is the increasing risk from extreme events, such as floods and droughts.

Floods in this context include riverine floods and flash floods resulting from river overflows, but also glacial lake outburst floods, as well as urban flooding caused by cloudbursts and intense, long lasting precipitation in areas with limited infiltration capacity. Today hydrological disasters claim the largest number of human victims and economic damage in comparison to other types of disasters. From 2004 – 2013 the average number of victims of hydrological disasters worldwide was more than 90 million annually, with annual economic damages of more than 30 billion USD (Guha-Sapir, Hoyois and Below 2015). Notably, these numbers only account for floods and mass movement of hydrological origin, and does not include the damage incurred from droughts (meteorological), the scale of which is only marginally smaller.

Climate related factors, including sea level rise, are further increasing exposure globally to this set of impacts. Notable examples are coastal megacities, where urban flooding risks from intense rainfall combine with risks from storm surges related to sea level rise. Infrastructure investments that help increase capacity to mitigate these risks are key to reducing loss of human life and economic damage.

FIGURE 2
Number of floods 1986 - 2015 (EM-DAT 2015).



Centre for Research on the Epidemiology of Disasters, CRED.
Author : Alizée Vanderveken, Research Assistant at CRED.
Projection : WGS84 / Classification : Jenks.
Source : EM-DAT (2016), GAUL (2016), ESRI (2016).

1.3 THE ROLE OF CLIMATE CHANGE ADAPTATION TECHNOLOGIES

Climate change is affecting the hydrological cycle on all scales. Strengthening the ability to adapt to these changes is central to sustainable development and the survival of communities worldwide.

The urgency of addressing the growing global water challenges is also recognized by the business community. The World Economic Forum's 2015 edition of the Global Risks report identified risks related to water crises as number one global risk in terms of impact. Appropriate adaptation solutions play a key role in building resilience to manage these risks for all stakeholders.

Technology Needs Assessments (TNAs) for Climate Change², conducted within the framework of the UNFCCC and its Technology Mechanism, and guided by the Technology Executive Committee (TEC), have been carried out in more than 85 developing countries to date (UNFCCC 2013). More than 75% of countries that have completed their TNAs have identified the water sector as a priority sector in need of adaptation interventions, surpassed only by the need for adaptation in agriculture – a sector which relies heavily on sustainable water delivery. The parties to the UNFCCC also identify water as a priority area for action, with 119 Parties indicating water as a priority for adaptation action in the adaptation component of their intended nationally determined contributions (INDC). Fortunately, there are a number of ways in which appropriate infrastructure and technology can help mitigate climate related risks and vulnerabilities in water sector. This guide focuses on opportunities for adaptation to climate change induced hazards and building resilience by identifying water adaptation technologies that are relevant to the water management challenges outlined in the previous sections.

In broader terms, adaptation technologies can be classified as (Christiansen, Olhoff and Trærup 2011) :

- Hardware – refers to the 'hard' technologies, i.e. physical infrastructure and technical equipment on the ground ;
- Software – refers to 'soft technologies', i.e. approaches, processes and methodologies, including planning and decision support systems, models, knowledge transfer and building skills necessary for adaptation ;
- Orgware – the organisational technologies, i.e. the organizational, ownership and institutional arrangements necessary for successful implementation and sustainability of adaptation solutions.

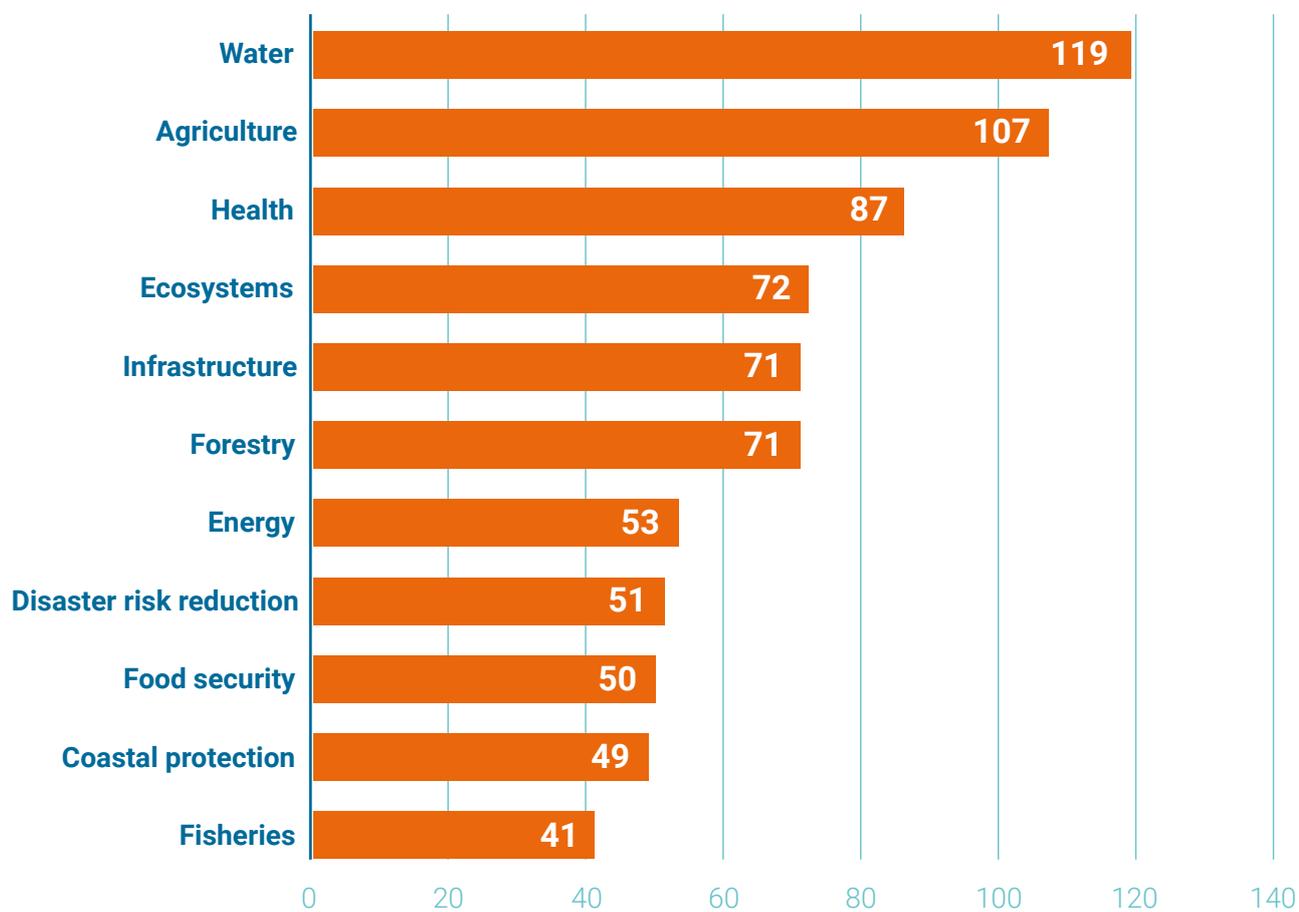
In the context of this guide, water *adaptation technologies* will include both implementation of technological tools and equipment, and approaches and management strategies relevant to climate change adaptation. Thus, the focus will be on *hardware* and *software* technologies. *Orgware* is briefly addressed through the dimensions of Integrated Water Resources Management that are of particular importance for water technology selection and implementation. However, no further technologies for *orgware* have been included in this guide. Governance and organizational approaches often require individual models designed to fit the very specific socioeconomic and governance settings in each country, municipality or community. Furthermore, there are a number of *hardware* and *software* adaptation technologies included in this guide that require a certain level of institutional and governance framework readiness, for them to be utilized efficiently. Thus the needs for *orgware* may often have to be addressed simultaneously with the implementation of such technologies (e.g., in implementation of ecosystem-based adaptation approaches).

The overarching aim of this guide is to aid practitioners and decision makers working in the field of water resources or other sectors relying on the sustainable and predictable delivery of water ecosystem services to plan for and implement climate change adaptation strategies. It provides a comprehensive overview of specific water adaptation technologies that address water resources challenges resulting from climate change. These are organized in a water adaptation technology taxonomy grouped into six broader categories of adaptation challenges and the specific adaptation technology responses within each.

² Technology Needs Assessments or TNAs are undertaken to determine country climate technology priorities. Since 2001, more than 80 developing countries have conducted TNAs to address climate change. In recent years, many countries have also identified their climate technology needs in their nationally determined contributions (NDCs). More on TNAs and NDCs at : <http://unfccc.int/ttclear/tn>

FIGURE 3

Number of Parties that referred to an area or sector as a priority in adaptation actions communicated in the adaptation component of the INDCs (UNSTATS 2017).



2. THE NEED FOR INTEGRATED APPROACHES TO WATER ADAPTATION PLANNING

On a broader level this guide creates an overview of water adaptation technologies that help to :

- Identify and understand specific climate change related water problems and their extent ;
- Analyse and map specific water-related climate vulnerabilities and associated risks to communities and ecosystems ;
- Evaluate potential adaptation responses and relevant technologies ;
- Implement specific measures and technologies ; to mitigate the problem(s) at hand ;
- Establish broader integrated management frameworks that help plan for, and make use of, all technological opportunities for adaptation in a coordinated way.

An integrated and comprehensive adaptation response plan or programme should strive to consider all of the above aspects and their mutual interactions in the process of adaptation technology selection and implementation.

The inherent complexity of land-water-energy interactions creates a need for integrated approaches to adaptation in water sector. It is widely acknowledged (United Nations 2012) that integrated approaches to resource management and development are necessary, and represent best practices in the quest for sustainable development. However, such approaches also pose a new level of complexity that has to be addressed by water managers, as well as practitioners from related sectors (see more on key water users in chapter 1.2). This requires better understanding of water interdependencies with other sectors – from the physical interactions of water flows across various sectors to policy and management for creating frameworks for integrated resource governance and management.

Integrated Water Resources Management (IWRM) is an approach to water resources management that promotes development and management of water, land and related resources in an integrated way (in order to maximize economic and social benefits), an equitable way, and without compromising the health of ecosystems (GWP 2010). Thus the IWRM approach is an alternative to the traditional sector-by-sector management paradigm, where uncoordinated use can

lead to rapid resource depletion and pollution.

A central aspect of IWRM is equitable distribution of benefits and stakeholder involvement in the planning and management processes. In the context of climate change adaptation these aspects are crucial, as the impacts of climate change are often felt the most by the poor and vulnerable. The types of approaches that IWRM promotes – including flexible water allocation between various uses, stakeholder participation, information sharing and basin level planning – at their core comprise relevant adaptation responses in many communities (e.g. implementing water allocation measures to cope with changing precipitation patterns). Importantly, in the context of climate change and shifting water availability, the integrated approach to water resources use and development helps to build resiliency, including better preparedness for extreme events such as floods and droughts.

Thus the selection and implementation of a specific water adaptation technology is best done within integrated planning and management frameworks. Understanding the links, as well as the implications, of such interventions on related user sectors could help to not only create better opportunities for maximizing cost efficiency through single or multipurpose adaptation investments, but also avoid unintended consequences.

In practice, implementation of IWRM is challenging, and more often than not translates to a continuous process of improvement, rather than an end. Integrated planning requires dialogue with a multitude of stakeholders, as well as an agreement on common strategic priorities. In order to succeed, appropriate governance, management and technological tools are critical. For example, data relevant to quantifying water resources, such as water supply and demand, are often fragmented, and if available, are held by a variety of stakeholders, from environmental ministries to energy authorities and private players. The lack of a common, systematic overview of sectoral interactions or water use in a given hydrological unit (or country) can prevent meaningful assessment of the most appropriate and efficient adaptation interventions. For example, improved industrial water efficiency will not yield the expected results in water availability in a basin if no steps are taken to address subpar agricultural water efficiency. Similarly, investing in downstream wetlands for water treatment will be less efficient for basin health if no measures are

put in place for protection of source water from pollution.

Decision Support Systems (DSS) are one example of tools that can help create a common knowledge platform for the various users. DSS are typically computer-based information systems that help merge data, various relevant socioeconomic variables, scenarios (climate change and socioeconomic development) and decision support tools. Typically a water resources decision support system would integrate information system modules, one or more hydrological modelling and scenario development modules and decision-making tools.

In the context of water resources management and adaptation, DSS can help systemize relevant water data from a number of sectors to create a better understanding of the status of resources and relevant uses and users within a given system, as well as help explore various (adaptation) interventions scenarios and their impacts on the system. At their core, Decision Support Systems serve as a science and policy interface (Giupponi and Sgobbi 2013) by bringing together social concerns and priorities, as well as a scientific basis for decision-making that together inform various scenarios of action.

The following chapters of this guide present an extensive catalogue of adaptation technologies that could, individually or combined, form a portfolio of interventions for water resources adaptation. Regardless of the adaptation response and technology selected, planning and implementation should take place within the framework of integrated resource management, to the extent possible.

3. HOW TO USE THIS GUIDE

The focus of this guide is adaptation technologies relevant to ensuring a sustainable supply of clean and sufficient water, as well as management of water-related disasters.

This guide takes current climate-related water challenges as an entry point to identifying relevant water adaptation technologies. It is structured around **six broad water challenges** relating to climate change:

1. **Unknown climate risks** – understanding, quantifying and analysing the risks and hazards, as well as the specific vulnerabilities created by climate change, in relation to water resources.
2. **Too little water** – response options and climate adaptation technologies for managing and adapting to water scarcity, droughts and water shortages.
3. **Too much water** – response options and specific climate adaptation technologies to manage and adapt to floods.

4. **Water pollution** – response options and specific adaptation technologies to address water quality challenges.

5. **Sea level rise** – response options and climate adaptation technologies for managing and adapting to coastal risks related to climate change, and sea level rise (such as increased intensity of storms, flooding, and saltwater intrusion).

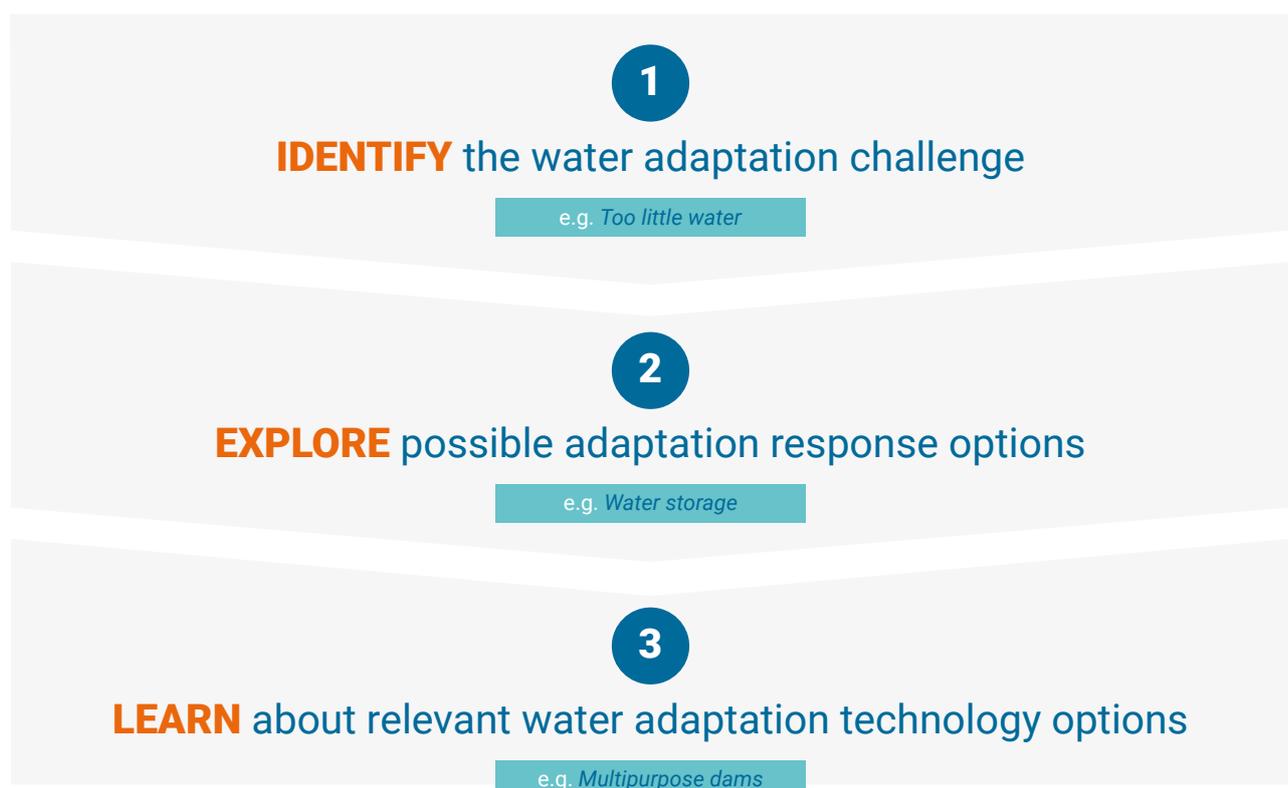
6. **Disaster preparedness** – response options for improved disaster preparedness and the corresponding adaptation technologies.

For each of these challenges a suite of possible response options is presented. Furthermore, for each of the response options a number of specific adaptation technologies are listed for consideration and evaluation.

A simplified structure of the process for finding the appropriate water adaptation technology is presented in the figure below.

FIGURE 4

How to use this guide.



For clarity, working definitions of this guide's main building blocks are explained below :

- 1. Water adaptation challenge:** the overarching water management problem that requires a solution in the context of water management for adapting to climate change.
- 2. (Adaptation) Response options:** The possible actions that can be taken to adapt to or solve the problem.
- 3. Adaptation technologies** – The specific technological means to execute the response/action on the ground. This can include 'hard' technologies (e.g. construction of specific infrastructure, application of software, etc.) and 'soft' technologies (e.g. applying specific planning and management approaches and methods).

This guide covers the typologies of the water adaptation technologies and does not provide details on its specific variations. For example, the water adaptation technology for alternative water sources, desalination, does not account for various technological variations within desalination technologies (membrane desalination, thermal desalination, etc.).

Figure 5 presents the full overview and taxonomy of the water adaptation technologies included in this guide.

FIGURE 5

Water adaptation technology taxonomy.

CLIMATE CHANGE ADAPTATION TECHNOLOGIES FOR WATER		
UNKNOWN CLIMATE RISKS	TOO LITTLE WATER	TOO MUCH WATER
Hazard and risk assessment	Water allocation	Riverine flood protection
Downscaling of climate model projections	Basin level modelling and seasonal forecasting	Structural barriers to flooding - dams, dikes, locks, and levees
Disaster risk assessment using LIDAR	Seasonal water rationing	Optimization of reservoir operations
Flood hazard assessment and mapping	Water re-allocation	Re-connecting rivers with floodplains
Drought risk assessment and mapping		Flow-through dams
Vulnerability assessment	Water augmentation	Accommodation of flooding (flexible buildings and infrastructure)
Socio-economic scenarios	Rainwater harvesting for infiltration	Ecological river restoration
Climate change vulnerability assessments	Urban green spaces	Multipurpose dams
Decision scaling	Conjunctive use of surface and groundwater	Zoning and land development limitations
	Managed aquifer recharge (MAR)	
	Source water protection	
	Water efficiency and demand management	Urban storm water management
	Water efficiency in industry	Urban green spaces
	Improved irrigation efficiency	Permeable pavements and parking lots
	Water metering	Bioswales
	Reducing system water loss and leakages	Optimization of urban drainage systems
	Public water conservation campaigns	Runoff control structures to temporarily store rainwater
	Progressive pricing	
	Hydrological zoning	Glacier lake outburst prevention
	Water licencing and permits	Artificial lowering of glacial lakes
	Shifting the timing of use	
	Water savings requirements in building codes	
	Water storage	
	Surface reservoirs	
	Multipurpose dams	
	Soil moisture conservation techniques	
	Natural wetlands	
	Rainwater harvesting for storage	
	Alternative water sources	
	Sea water desalination	
	Solar water distillation	
	Fog harvesting	
	Interbasin transfers	
	Groundwater prospecting and extraction	
	Boreholes and tubewells	
	Water recycling and reuse	

WATER POLLUTION	SEA LEVEL RISE	DISASTER PREPAREDNESS
Limiting nutrient leakage	Limiting saltwater intrusion	Early warning
Riparian buffers (e.g. wetlands, buffer strips)	Limiting abstraction from shallow aquifers	Flood forecasting systems
Protected areas and land use limitations	Barriers to fluvial saltwater intrusion	Drought forecasting systems
Change in agricultural practices (limiting fertiliser application, sediment control)	Increasing sustainable aquifer recharge	Early warning systems for floods
Saltwater intrusion	Coastal groundwater level monitoring	Landslide and mudflow warning systems
See section <i>Sea Level Rise</i>	Coastal surface water monitoring	Decentralized community run early warning systems
Mitigating pollution at source	Built infrastructure for shoreline protection	Drought early warning systems
Source water protection	Revetments	Flash flood guidance systems
Water safety plans	Sea walls	Real-time monitoring networks
Flood proofing for water quality	Land claim	Disaster response
See more in section <i>Urban storm water management</i>	Beach nourishment	Stacking of sandbags combined with the use of ground improvement technology
Flood-proof wells	Storm surge barriers and closure dams	Flood Disaster Preparedness Indices (FDPI)
Flood-proof sanitary latrines	Breakwaters	Communication protocols
Improved water treatment capacity	Dikes	Flood shelters
Advanced domestic wastewater treatment tanks	Groynes	Social media applications for disaster response and mapping
Constructed wetlands for water treatment	Jetties (inlet structures)	National and community disaster management plans
Improved efficiency of centralized water treatment systems	Green infrastructure for shoreline protection	
Improved point-of-use water treatment	Artificial reefs	
	Restoration and protection of coral and oyster reefs	
	Cliff stabilization	
	Sea grass beds	
	Coastal wetlands (including mangroves)	
	Dune construction and rehabilitation	
	Accommodation and management	
	Coastal zoning	
	Floating agricultural systems	
	Flood proofing	
	Managed coastal realignment	
	Coastal setbacks	
	Fluvial sediment management	

3.1 WATER ADAPTATION TECHNOLOGY BRIEFS

Subsequent sections of this guide explore and explain each of the areas of water adaptation challenges, as well as their respective adaptation response options, in more detail. For each possible response to an adaptation challenge, a number of specific adaptation technologies are introduced. While this list is not exhaustive, 102 water adaptation technologies are included in this guide.

Water adaptation technology briefs were prepared for each of the technologies included in this guide. These can be downloaded from the dedicated pages on the Climate Technology Centre and Network (CTCN) knowledge management system³.

It is important to note that many more adaptation technologies are likely to be relevant to management of climate change impacts on water resources. Examples include infrastructure vulnerabilities such as drinking water reservoirs, water treatment plants, but also risks to roads, ports and bridges in relation to coastal and riverine flooding or sea level rise. These challenges may require implementation of specific adaptation technologies pertaining to the design of the infrastructure itself, which requires site and design related analyses that are beyond the scope of this guide. These actions are also likely to fall outside of water managers' scope of responsibilities. Nevertheless, an integrated approach to climate adaptation planning that includes appropriate infrastructure planning and development units is always strongly encouraged.

New innovations in climate change adaptation technologies are emerging on a nearly daily basis, and therefore the taxonomy presented in this guide will need to be reviewed as new technologies emerge. To keep up to date, users are encouraged to explore the CTCN website and its technology library⁴ for emerging climate change adaptation technologies in the water and other related sectors (see Box 1 on Water adaptation technology briefs).

Box 1 : Water adaptation technology briefs

To provide further information on each of the 102 water adaptation technologies introduced in this guide, short technology brief was developed for each of the technologies.

Each water adaptation technology brief includes following information :

Description – brief introduction to the technology

Implementation – brief account of main steps pertaining to the implementation of the technology

Benefits – account of the most important environmental and socioeconomic benefits

Opportunities and barriers – account of the most significant barriers and opportunities in relation to the technology

Implementation considerations – relative assessment (on a scale of 1 to 5) of considerations of implementation relating following dimensions: Technological maturity, initial investment needs, operational costs and implementation timeframe.

You can download water adaptation technology briefs from the direct links embedded in this document, or directly from CTCN's knowledge management system via : <https://www.ctc-n.org/resources/climate-change-adaptation-technologies-water-practitioner-s-guide-adaptation-technologies>

³ <https://www.ctc-n.org/resources/climate-change-adaptation-technologies-water-practitioner-s-guide-adaptation-technologies>

⁴ <http://www.ctc-n.org/>

4. WATER ADAPTATION TECHNOLOGIES

4.1 CLIMATE RISKS AND UNCERTAINTY

Risk and uncertainty are inherent challenges for any water manager, as well as any adaptation technologies investor, and these challenges are exacerbated by climate change. However, they can be reduced by implementing adaptation technologies that help better understand and evaluate the impacts of climate change on the water resources of a given river basin, community, location or ecosystem. The most appropriate adaptation responses and technologies can then be identified through improved understanding of impacts and their distribution.

This guide identifies two overall adaptation responses for tackling risk and uncertainty in the water sector – **Hazard and risk assessments** and **Vulnerability assessments**. Together, these cover the crucial steps leading up to the identification and affirmation of appropriate adaptation technologies, providing the necessary diagnostic analysis for informed action.

Living with the risks of various climate related challenges is not a new phenomenon in many communities across the world. Seasonal floods, for example, are part of the hydrological cycle in many river basins. Climate change, however, is likely to exacerbate these challenges and increase both the severity and unpredictability of the seasonal water flow changes, including changing distribution and severity of extreme weather events. Understanding these emerging and increasing hazards, as well as assessing the level of risk they present to communities, is essential for any water manager to identify and design the best possible adaptation strategies and actions, as well as secure investment for their deployment.

A well-designed climate change **Hazard and risk assessment** helps to establish linkages between regional climate change and its impacts at the local level, and identifies the specific risks to the water resources sector that need to be addressed. This includes impacts on water resources availability and quality, as well as identification of locations and communities⁵ particularly vulnerable to extreme events.

Essentially, hazard and risk assessments attempt to quantify the impacts of climate change on water resources and their (likely) geographical and temporal distribution, based on historic patterns and today's best available science.

It is important to note that there are many caveats to be considered when using downscaled and modelled climate change data for hazard and risk assessment, and especially so for localized applications. These can be used for adaptation intervention planning and can provide valuable information, but the assumptions and uncertainties associated with methods themselves need to be understood and weighed carefully. Supplementary information is usually required to validate and support such datasets.

Vulnerability assessments, on the other hand, look at the interaction between climate change impacts and the characteristics of the area, economic activity, ecosystem, or community in question. Vulnerability thus becomes a function of the potential impacts of climate change (exposure) and that of the characteristics of the system (sensitivity to the changes) and the ability of the system to deal with the impacts (adaptive capacity) (GIZ 2014). This also means that vulnerability is a less static element, and can change over time. Implementing appropriate adaptation technologies can reduce it.

Table 1 summarizes adaptation technologies relevant for addressing Climate Risks and Uncertainty that are included in this guide. There are a growing variety of approaches and methods for both hazard and risk assessments and vulnerability assessments. This guide aims to explain the basic thinking and rationale behind the overarching approaches, with some pointers to possible starting points.

However, it is not prescriptive, and it is up to the reader to explore the approaches in detail to identify what is most appropriate for the given needs.

⁵ On policy and management level, these efforts have a close link to disaster risk management.

TABLE 1
Adaptation technologies for tackling unknown climate risks.

UNKNOWN CLIMATE RISKS			
Adaptation response	Technologies	Description	Technology description brief
Hazard and risk assessment	Downscaling of climate model projections	Methods of estimating local scale climate change impacts based on information derived from regional and global climate models. Fundamental in modelling and understanding future climate impacts on water resources. Typically coupled with other sources of information and models, due to high level of uncertainties in, particularly, local scale results.	<u>Download</u>
	Disaster risk assessment using LIDAR	LIDAR (Light Detection and Ranging), is a remote sensing method that can be used to generate detailed maps of topography and retrieve digital elevation data necessary for flood modelling and vulnerability and risks analysis. It uses a pulsed laser to measure and record three-dimensional information on the surface of the earth (topographic LIDAR), or the seafloor or riverbed (bathymetric LIDAR). The equipment is usually installed on an airplane, helicopter, or other airborne device, and includes a laser, scanner and GPS device.	<u>Download</u>
	Flood hazard assessment and mapping	Technology (-ies) used to identify areas at risk of flooding, and consequently to improve flood risk management and disaster preparedness. Typically look at the expected extent and depth of flooding in a given location, based on various scenarios (e.g. 100-year events, 50-year events, etc.). Flood hazard assessments can be further expanded to assess specific risks, which take into consideration the socioeconomic characteristics (e.g. industrial activities, population density, land use) of the exposed areas.	<u>Download</u>
	Drought risk assessment and mapping	A key element of drought management as it helps identify the areas most at risk of droughts, allowing communities to plan, as well as prepare for and mitigate possible impacts. Drought risk is calculated as the probability of negative impact caused by interactions between hazard (probability of future drought events occurring based on past, current and projected drought conditions), exposure (scale of assets and population in the area) and vulnerability (probability of assets and population being affected by droughts in the area). Hydro-meteorological or hydrological indicators are commonly used to assess drought risks.	<u>Download</u>
Vulnerability assessment	Socio-economic scenarios	Socio-economic scenarios are various models that represent assumed developments in key socio-economic drivers. The scenarios are used to characterize the social and economic forces driving climate change, in addition to projecting the vulnerability and/or adaptive-capacity of socio-economic systems to the impacts of climate change. They help identify priority areas for interventions, and, coupled with hydrological and climate assessments, provide greater detail to risk assessments and quantification, in addition to climate impacts and possible adaptation responses.	<u>Download</u>
	Climate change vulnerability assessments	Establish understanding of the extent to which changing climate will affect the system in question. Vulnerability assessment methods go beyond the immediate hazards stemming from changes in temperature and rainfall (exposure), assessing also the characteristics of the system itself (sensitivity), as well its ability to deal with the anticipated impacts (adaptive capacity). In the context of water resource management, vulnerability assessments primarily focus on the climate risks to meeting increasing water demands under changing climate, and creating preparedness to increased climate variability (including extreme events such as floods and droughts). There are numerous frameworks and methods for vulnerability assessments and the selection of the best method should be based on locally relevant criteria, which may include purpose, information availability, costs, assessment priorities etc.	<u>Download</u>
	Decision scaling	Approach to climate risk and vulnerability assessment that couples inputs from stakeholders and climate projections. Central to decision scaling is use of data analytics, coupled with stakeholder engagement to understand key sensitivities and uncertainties, and identification of robust response approaches.	<u>Download</u>

4.2 TOO LITTLE WATER

The changing variability of rainfall patterns and rising temperatures associated with climate change is expected to contribute to increased frequency of water scarcity and droughts (UNFCCC 2014). The risk of water scarcity is exacerbated by socioeconomic drivers such as population growth, economic development and associated increases in per capita water use, as well as expansion of agricultural and industrial activities (IPCC 2014).

Reduced flows and increased water stress have strong links to ecosystem health and water quality. Thus, mitigating water scarcity contributes not only to greater physical resource availability, but also sustained ecosystem health and nearly all socioeconomic activity, including energy production, agriculture and food production and industrial activity.

In general, water scarcity can be linked to two core drivers - natural and human. Water scarcity originating from natural factors can be a result of lower than usual precipitation and freshwater flows, leading to a physical lack of water. For example, many rivers experience seasonal variations in flows, and as a result flows in the dry season are no longer sufficient to sustain optimal human and ecosystem activity. This seasonal variability of rainfall is expected to increase in many areas, often making dry seasons more dry and wet seasons more wet.

Water scarcity can also be, and often is, caused by unsustainable resource use, whether or not the physical availability of water and rainfall patterns have changed. Competing demand and over-abstraction of groundwater and surface water, along with uncoordinated resource development, are common causes of water scarcity in many regions. Over-abstraction can lead to more acute water crises as it leads to degradation of the sparse resources that remain – e.g. salinization of groundwater or increased nutrient pollution due to the reduced ability of freshwater to dilute pollutants.

Communities need to be able to sustain their livelihoods and socioeconomic activities in a way that also maintains a sufficient supply of water in the dry season, or during droughts. To do so, it is necessary to plan for and implement adaptation technologies that can help optimize use of existing, finite, resources, as well as reduce demand. Some of the key adaptation response options to water scarcity are outlined below.

Improved **water allocation** agreements are key to efficient use of limited resources and ensuring that resource development is better coordinated, thus reducing risk of over-abstraction and ecosystem degradation. Water allocation as a climate change response aims to implement technologies and

establish arrangements for sharing existing resources among users in a way that is equitable, and to ensure maximum benefits for all, including the environment. This is relevant for all sources of freshwater, including surface and groundwater. An important precondition for efficient water allocation is understanding inputs and abstractions in relation to the entire river basin or water body in question, including the quantification of availability and demand for various users, as well as the value that various uses create for society. This information can support decisions for optimal allocation. Stakeholder dialogues should be part of all water allocation projects, given that often compromises have to be negotiated among competing uses and users.

Water augmentation in turn aims to increase the available supply of freshwater through active recharge or protection, or water recharge areas. Increased urbanization and land conversion, along with changing climate, affects the natural cycle of aquifer recharge. Natural recharge of groundwater takes place when surface water is able to percolate through soil and vegetation to reach an underground water table originating from rain or surface stream flow. Maintaining a sufficient groundwater table also mitigates saltwater intrusion. In recent decades, urban development and other land conversion activities have reduced the extent of permeable surfaces for groundwater recharge, due to buildings, asphalt and other hard construction that does not allow for water to percolate through soil. Water augmentation as an adaptation response aims to restore opportunities for increased water capture and infiltration by creating green spaces for improved natural recharge from rainfall. Another option for augmentation can be managed recharge, such as water injection in existing aquifers.

With predicted changes in the length and intensity of dry and wet seasons, **water storage** is one of the most important adaptation response options for coping with water scarcity. Some areas may experience decline in precipitation, while in others, even with an overall increase, rain may fall more intensely and over shorter periods, extending dry spells (McCartney and Smakhtin 2010). This will necessitate adaptation responses that use water storage to sustain agricultural and other socioeconomic activity even in the dry season. There are opportunities within both smaller and larger scale water storage technologies, to this effect.

When resources are scarce, it is important to address not only the available supply, but also the demand that often drives water scarcity. **Water efficiency and demand management** measures help reduce inefficient use and waste of freshwater through improved technologies and better oversight of water use. Addressing high per capita water use, system losses and inefficient use can make a great

difference in reducing water demand and use in many communities. This can be done through a variety of measures that include improving use efficiency through improved technologies (e.g. increased efficiency in irrigated agriculture), increasing incentive for water savings, or regulatory requirements that set standards for acceptable water use limits. Compared to other adaptation responses, these often employ relatively low-cost technologies. Successful implementation, however, requires a high level of engagement from stakeholders, including the general public. Therefore, awareness raising and education often play an important role in successful implementation of such approaches.

Even with successful implementation of water supply and demand measures, there are regions where water scarcity requires looking toward **alternative water supply sources**. Examples can be found in many Middle Eastern and North African countries, and island states, where freshwater is often not renewed enough to sustain growing populations. This creates a need for new sources of freshwater beyond surface and groundwater utilization. Alternative water sources that are rapidly developing and being applied include desalination of seawater and re-use of wastewater, though other options are also available.

Table below introduces the water adaptation technologies relevant for addressing these challenges.

TABLE 2
Adaptation technologies for Too little water.

TOO LITTLE WATER			
Adaptation response	Technologies	Description	Technology description brief
Water allocation	Basin level modelling and seasonal forecasting	A planning instrument (or set of instruments) to help optimize water allocation in a river basin among competing water uses. A combination of hydrological and economic models are typically utilized, first to estimate total water availability, which can then be used to assess environmental and economic impacts of different allocation management scenarios in the basin. This can helping decision makers gain an overall picture of current water use trends, and to make optimal (and sustainable) water management plans for the basin. A wide array of models is available.	Download
	Seasonal water rationing	An approach to control water use rates amongst different users based on the seasonal availability of water and socioeconomic priorities. Rationing may take the form of water use restrictions for certain purposes, in certain times, or certain areas. The aim is to maintain equitable use among different users, as well as high levels of water productivity, throughout the year.	Download
	Water re-allocation	The transfer of use rights between users who have been allocated a certain amount of water (through formal water use rights or entitlements, or informal arrangements), after it has been determined the initial allocation is physically impossible, or socioeconomically unfavourable. Resource re-allocation can help adapt to unforeseen circumstances (e.g. critical water shortages during the dry season), reduce stress on renewable water supplies and help optimize water use benefits. Can either be voluntary or non-voluntary.	Download
Water augmentation	Rainwater harvesting for infiltration	Also known as in situ water harvesting, this is a practice in which rainwater uptake in soils is increased through the soil surface, rooting system and groundwater. Soil effectively acts as the storage agent, which improves water holding capacity and fertility and reduces risks of soil loss and erosion. Examples include terracing, pitting and conservation tillage.	Download
	Urban green spaces⁶	Green spaces are areas covered by vegetation (e.g. grass, bushes or trees). Particularly relevant in urban settings, where they help to uptake and infiltrate water, decreasing runoff rates, which also often contain excessive amounts of pollutants. This subsequently reduces the pressure on water drainage systems and treatment facilities. The high water retention capacity of vegetation makes them important for mitigating floods and managing urban storm water, and in creating opportunities for groundwater recharge.	Download

⁶ Also included in chapter Too much water, as this technology has relevance for storm water management.

Water augmentation	Conjunctive use of surface and groundwater	The combined use and development of surface water and groundwater. Aims to increase the overall resilience of water supply by utilizing both sources of water, particularly in communities and basins with high water variability throughout the seasons. It often focuses on the advantageous role of groundwater for water storage, distribution and treatment (through biological processes).	<u>Download</u>
	Managed aquifer recharge (MAR)	Water management approach that can be used to maximize natural storage and increase water supply system resilience during periods of low flows and high seasonal variability. During these periods aquifers are intentionally recharged to recover water. A managed recharge implies that the recharge process is controlled and ensures health and environmental risks are minimized.	<u>Download</u>
	Source water protection⁷	Entails measures that restrict overuse and pollution of water at its source, and may include regulations (e.g. water allocation quotas, water quality compliance regulations), compensation schemes (e.g. payments to industrial or agricultural users to reduce use of pollutants or extraction volumes, payments for ecosystem services schemes) or conservation measures in the upstream watershed. These include measures to maintain optimal water recharge and infiltration in upstream areas.	<u>Download</u>
Water efficiency and demand management	Water efficiency in industry	Behavioural, operational and technological changes for improved water efficiency in industrial production. Includes more effective leak detection and repair of water pipes and use of new and more efficient technologies (e.g. pipes, smart dosage systems, timers, higher efficiency cleaning systems, water monitoring systems). Increasing awareness and changing behavioural patterns can also reduce water consumption amongst workers. On a regulatory level, industrial water efficiency can be encouraged by establishing tariffs as a water conservation incentive.	<u>Download</u>
	Improved irrigation efficiency	Aims at minimizing water use within the agricultural sector while continuing to maintain optimal crop productivity rates. Technologies include more efficient irrigation systems where water release can be controlled so that crops receive only the amount needed (e.g. pressurized irrigation systems such as drip irrigation). Other modern irrigation systems are self-propelled and include wireless sensors and GPS technology to improve site-specific and volumetric precision of water applications to match the needs of the soil and crops. Irrigation efficiency can also be improved through altering farming practices, such as crop rotation (plant crops according to seasons and soil conditions) and conservation tillage (leaving a previous year's crop residue on the field to reduce soil erosion and runoff) that help improve soil moisture conservation.	<u>Download</u>
	Water metering	A method, including necessary equipment, that helps users to account for water consumption rates that are often coupled to pricing charges per unit consumed. Often a component of public water resource management aimed at monitoring and eventually reducing water consumption. Can additionally be used to detect and pinpoint leakages in the system (water produced compared to water metered at the end point), and provides information to utilities about consumer behaviour that can be used in water conservation campaigns.	<u>Download</u>
	Reducing system water loss and leakages	Measures to improve efficiency in distribution systems and avoid unnecessary withdrawals. 'Real' water losses are defined as the amount of water lost between the supplier and the consumer, while 'apparent' losses are defined as those due to inaccurate consumption measurements by the consumer or utility. Implementing leak detection systems, pressure control, maintaining meters, and controlling against unauthorized use, are all measures that can help mitigate real and apparent water losses (also known as non-revenue water).	<u>Download</u>
	Public water conservation campaigns	Aim to change citizen attitudes and behaviour to improve water use efficiency. Includes education and awareness campaigns on the socioeconomic and environmental benefits of water conservation and different conservation methods. Communication means include traditional and social media, as well as direct communication such as workshops, presentations, stakeholder dialogues, etc.. Economic incentives can also be employed, for example, free installation of water meters.	<u>Download</u>

⁷ Also included in chapter Water pollution, as this technology has relevance for pollution management.

Water efficiency and demand management	Progressive pricing	An economic instrument to manage water demand and help reduce excessive water consumption through an economic dis-incentive. Progressive pricing means that water price rates per unit of volume increase, as the volume used increases. Thus the largest consumers of water pay higher rates for the volume of water consumed beyond a certain threshold.	<u>Download</u>
	Hydrological zoning	An approach to divide land into different zones based on their hydrological properties. Typically, each type of zone has different land use and development regulations linked to it. Aims to protect local water sources from risks of over-abstraction, land salinization, groundwater pollution and waterlogging by managing land use activities based on the assigned hydrological zones. Such restrictions may limit irrigation to avoid nutrient loading and sediment runoff into watersheds, but can also limit other activities such as industrial discharge and water abstraction from surface or groundwater sources.	<u>Download</u>
	Water licencing and permits	A water demand management tool requiring private landowners, or at times specific potential water users, to apply for (or purchase) a license or permit for water-use or water affecting activities (e.g. construction, diversion, artificial recharge) in the watershed. Water licensing allows authorities and watershed managers to keep track of how much water is used, where and by whom, imposing timely restrictions where needed.	<u>Download</u>
	Shifting the timing of use from peak to off-peak periods	Approach to water demand management that aims to reduce or reschedule peak water withdrawals or consumption from either surface or groundwater, prioritizing the most beneficial and strategically important water uses.	<u>Download</u>
	Water savings requirements in building codes	A legislative approach to improve water use efficiency in commercial and residential buildings. The building codes may require installation of modern technologies such as water pressure control, faucet aerators, leak detectors, water-saving toilets, etc. to maximize use efficiency, but can also require installation of internal water recycling systems or the establishment of infrastructure to provide alternative water sources, for example rainwater harvesting tanks.	<u>Download</u>
Water storage	Surface reservoirs	Built structures for water storage that help improve water security. The types and sizes of reservoirs vary, from damming natural water bodies for storage to ground excavation in low-lying plains fed either by rainwater or diverted rivers. Stored water can be used for numerous purposes, including irrigation, industry, domestic use, hydropower generation and flood control.	<u>Download</u>
	Multipurpose dams⁸	Dams that combine two or more functions of traditional single-purpose dams into one hydro infrastructure project. A multipurpose dam may combine storing and supplying water for irrigation, industry and human consumption with other uses such as flood control, power generation, navigation, runoff storage and water discharge regulation.	<u>Download</u>
	Soil moisture conservation techniques	Approaches and techniques (usually in agricultural practices) that aim to mitigate soil moisture stress and reduce direct evaporation, and increase the water holding capacity of the root zone.	<u>Download</u>
	Natural wetlands	Utilization of wetland ecosystem services for climate benefits. May include wetland restoration or conservation activities (avoided degradation). Wetland restoration is the reestablishment of a degraded wetland. Restoration interventions aim to restore the original hydrology and topography of the wetland so that natural processes and ecosystem services delivering water storage and regulation benefits can be maintained.	<u>Download</u>
	Rainwater harvesting for storage	Also known as ex situ water harvesting, this is a practice in which rainwater is collected and stored for productive use. The rainwater can be directly captured in open storage systems, but can also be collected from roofs, soil surfaces or roads. The most common storage devices for harvesting rainwater are tanks.	<u>Download</u>

⁸ Also included in chapter Too much water, as this technology has relevance for flood mitigation.

Alternative water sources	Sea water desalination	A process in which salt and other constituents are removed to produce pure water. The two most common forms of desalination are thermal treatment and membrane processes. Thermal treatment uses heat to evaporate the water, leaving behind the dissolved salts, or waste stream, and separating it from pure water. Membrane processes use reverse osmosis and high pressure to force saltwater through very fine, porous filters that retain the salts, leaving pure water on one side of the membrane and the waste stream on the other side.	<u>Download</u>
	Solar water distillation	Process of using the energy from sunlight to separate freshwater from salts or other contaminants. Solar water distillers are simple and relatively cheap technologies that provide alternative sources of freshwater in water stressed areas. Small and simple solar water distillers are usually built for single households, though larger systems can also be set up for shared use.	<u>Download</u>
	Fog harvesting	A technique used to capture water from wind-driven fog. Typically installed in areas where the presence of fog is naturally high, e.g. coastal and mountainous regions. The systems are usually constructed in the form of a mesh net, stabilized between two posts that are spread out at an angle perpendicular to the prevailing wind carrying the fog. As the wind passes through the mesh, drops of freshwater form and drip into an underlying gutter, from which pipes lead the water into a storage tank.	<u>Download</u>
	Interbasin transfers	The moving of water from a watershed with a surplus (donor basin) to a watershed suffering from a shortage (recipient basin). The water is transferred primarily to alleviate water scarcity in the recipient basin and travels long distances via complex pipeline and canal systems.	<u>Download</u>
	Groundwater prospecting and extraction	Involves various methods to locate suitable quality and quantity groundwater for extraction. Groundwater prospecting and extraction can both be part of general water resource management strategies to increase supply, or respond to climate change induced water scarcity or variability. Methods include hydrogeological investigations, geophysical surveys, remote sensing assessments, and the more simple method of investigating already existing well sites in the area and their depths and characteristics.	<u>Download</u>
	Boreholes and tubewells	Extraction of freshwater from subsurface or deeper groundwater aquifers. Can include creating new boreholes and tube wells (for example as a drought response measure), or deepening or rehabilitating existing ones.	<u>Download</u>
	Water recycling and reuse	Technologies for collecting, treating and using wastewater, particularly from municipalities, industry and agriculture. The recycled water can be used for irrigation or industrial purposes, as well as domestic use if properly treated. In some cases, treated wastewater is indirectly used for drinking purposes, for example by injecting it into groundwater aquifers to increase capacity and minimize saltwater intrusion.	<u>Download</u>

4.3 TOO MUCH WATER

Climate change is expected to contribute to increased rainfall intensity, as well as increased variability of seasonal distribution of rain. The growing temperatures mean that the atmosphere is able to hold an increasing amount of moisture, leading to higher potential rainfall volumes, and thus increased risks of flooding. In coastal areas, sea level rise will exacerbate dangers of tidal flooding (more on adaptation responses and technologies for coastal areas in chapter 4.5).

Communities will have to adapt to riverine floods, flash floods, urban floods and sewer overflows, as well as flood risks resulting from glacier lake bursts. Many countries have already experienced increased frequency and severity of flooding. Both climatic and non-climatic factors (IPCC, 2007) will affect the extent of flood impacts on human settlements and socioeconomic activities. The immediate impacts and damage of flooding depend on many factors,

such as soil character, wetness, urbanisation and land cover, in addition to existence of dikes, dams, or other flood prevention structures. However, the impacts also to a large extent depend on the concentration of socioeconomic activity in flood risk zones (densely populated areas vs. remote areas) and the general level of flood preparedness and response.

Riverine flood protection is not a new phenomenon and many communities face river floods (also known as fluvial flooding) on regular basis. Yet economic and human flood damages make it the costliest disaster type on a global scale. Riverine flooding occurs when the water holding capacity of a river is exceeded as a result of rainfall or snowmelt. Blockages in the flow along the watercourse can exacerbate flood risks, for example by breaching flood defences (RIBA 2009). Flash floods occur during heavy rainfall events and are particularly dangerous as the onset is quick and the velocity of water faster and more powerful. It is also more challenging to predict the occurrence of flash floods, as opposed

to seasonal flooding in floodplains. Population growth and urbanization are steadily increasing the number of human lives and assets at risk.

Surface water flooding (also known as pluvial flooding) in urban environments occurs when rainfall, particularly during extended intense rainfall events and cloudbursts, is not able to percolate through the soil and accumulates in areas with low absorption capacity. The increasing rates of urbanization and density of land developments contribute to increases in impervious surfaces. Water surface infiltration area is reduced, and combined with aging, or non-existent, storm water infrastructure (RIBA 2009), these conditions create an urgent need for improved urban storm water management measures for climate change adaptation. Urban flooding can be dangerous and devastating due to its rapid onset and the exposure of large populations (and assets) to risks in a relatively small area. Risks related to pluvial flooding also include combined sewer overflows (CSOs) that occur in cities where storm water collection systems are combined with domestic sewage and industrial wastewater systems. During heavy rainfall events the high volume of storm water can cause sewers to overflow, creating water pollution risks in nearby water bodies, as well as serious public health

risks (EPA 2016). The spread of waterborne diseases due to floods and other extreme events has been well documented by the World Health Organization (WHO)⁹.

One of the most direct impacts of climate change in mountain regions is melting ice and glacier retreat, which contributes to creation of new glacial lakes, as well as increasing the volume of water in existing lakes (ICIMOD 2011). The accumulating melt water puts glacial lakes at increasing risk from glacial lake outbursts. Glacial lakes are inherently unstable, and due to the volume of water and speed of outburst, the effects of glacial lake flooding events can be devastating, wiping away agriculture fields and houses, destroying important infrastructure (e.g. roads and hydroelectric power plants) and disrupting the life of communities for months. Due to climate change, the need for **glacial lake outburst prevention** measures is urgent in many mountain regions.

There are a variety of adaptation technologies that can be employed to mitigate flood damages, ranging from structural protection technologies to accommodation of inevitable flooding events. These technologies are summarized below¹⁰.

TABLE 3
Adaptation technologies for managing Too much water.

TOO MUCH WATER			
Adaptation response	Technologies	Description	Technology description brief
Riverine flood protection	Structural barriers to flooding - dams, dikes, locks, and levees	Flood protection infrastructure used to control river floodwater flow and protect communities against costly effects of inundation. Typically a permanent construction built at a designated point on a waterway's path to contain water on one side of the barrier. Dams, dikes, locks and levees are common examples of such hard infrastructure.	<u>Download</u>
	Optimization of reservoir operations	Aims to ensure that all planned reservoir objectives are met, without compromising those of ecological water requirements. It takes into account a variety of objectives and variables, including cost and revenue considerations of water allocation for various socioeconomic uses. Various computer simulation models can be used for optimization. The models use algorithms to calculate the optimal balance between water release and reservoir storage volumes, adapting best strategy for flood risk reduction.	<u>Download</u>
	Re-connecting rivers with floodplains	A green infrastructure approach that focuses on removing barriers along the edges of the river. This allows the river to re-establish its natural course over time, eventually connecting to its historical floodplain, or creating a new one. It can include removal or setting back of levees, raising of a deeply engraved riverbed, or expanding a river's bank. Faster solutions include manually restoring (by digging) the river close to its original form, and establishing human made connections between the river and its original floodplain wetlands.	<u>Download</u>

⁹ <http://www.who.int/globalchange/summary/en/index5.html>

¹⁰ For coastal flooding protection adaptation technologies see chapter 4.5.

Riverine flood protection	Flow-through dams (also known as perforated dams)	Dams constructed solely for the purpose of flood control and mitigation of flood risks in downstream communities and ecosystems. The spillway (opening) is built at the same height as the riverbed level, allowing the river to continue its natural flow in normal conditions. When water levels rise above the spillway, the dam restricts the amount flowing through the opening, decreasing peak flood flow.	<u>Download</u>
	Accommodation of flooding (flexible buildings and infrastructure)	Design of infrastructure that can withstand the impact of flooding events, resulting in minimizing socio-economic damages and effective climate change adaptation. Accommodation techniques include flood resistant designs aimed at keeping floodwater out of the structure completely, and flood resilient designs, aimed at minimizing structure restoration costs and time if it is flooded. Includes, both, new designs or retrofitting existing structures.	<u>Download</u>
	Ecological river restoration	Involves ecological, spatial and physical management practices to return a river back (or close) to its natural state. Common restoration techniques include re-connecting rivers with floodplains, reestablishment of the river's meandering form with no barriers along its banks, and stabilizing surrounding soil to reduce sedimentation and erosion. Restored rivers have increased water retention capacity due to their ability to naturally expand their banks and flood onto floodplains, thus making them more effective for flood risk management.	<u>Download</u>
	Multipurpose dams¹¹	Dams that combine two or more functions of traditional single-purpose dams into one hydro infrastructure project. A multipurpose dam may combine storing and supplying water for irrigation, industry and human consumption with other uses such as flood control, power generation, navigation, runoff storage and water discharge regulation.	<u>Download</u>
	Zoning and land development limitations	This approach divides urban areas into zones with varying degrees of development restrictions depending on flood-risk level. Construction or reconstruction is often prohibited in high-risk areas, for example floodplains, while in other areas restricted development is permitted, given certain building regulations are followed.	<u>Download</u>
Urban storm water management	Urban green spaces¹²	Green spaces are areas covered by vegetation (e.g. grass, bushes or trees). In urban settings they help to uptake and infiltrate water, decreasing runoff rates, which also often contain excessive amounts of pollutants. This subsequently reduces the pressure on water drainage systems and treatment facilities. The high water retention capacity of vegetation makes them important for mitigating floods and managing urban storm water.	<u>Download</u>
	Permeable pavements and parking lots	Infrastructure designed in urban settings to facilitate storm water runoff and mitigate urban flooding and storm water overflow risks. Built to utilize ecosystem services provided by soil, allowing water capture and infiltration. The permeable surfaces provide greater water uptake. The water is infiltrated, and to an extent purified, before recharging the groundwater. The resulting retention decreases runoff rates and reduces pressures on urban storm water systems.	<u>Download</u>
	Bioswales	Strips of vegetated areas that redirect and filter storm water. A typical bioswale is a long, linear strip of vegetation in an urban setting used to collect runoff water from large impermeable surfaces such as roads and parking lots. Serve a similar purpose to that of gutters. The advantage of using bioswales is that the vegetation and soil slows down and collects water, allowing it to infiltrate soil, in addition to filtering pollutants.	<u>Download</u>
	Optimization of urban drainage systems	Improves existing drainage systems. Computer simulation models improve real time operations using algorithms to evaluate system performance, reveal deficiencies, identify high flood-risk areas, and illustrate optimal design improvement interventions such as optimal pump capacities, storage sizes, and locations, green spaces, etc.	<u>Download</u>
	Runoff control structures to temporarily store rainwater	Structures designed to capture runoff during peak flows, and can function as temporary storage sites. Typically built with a discharge component to slowly release water into the nearby waterway to avoid it overflowing from the storage basin. Can be artificially built, for example by excavating a large area so that it is lower than the surrounding land. Green spaces such as wetlands may also be utilized as temporary runoff storage structures.	<u>Download</u>

¹¹ Also included in chapter Too little water, as this technology has relevance for water storage.

¹² Also included in chapter Too little water, as this technology has relevance for water augmentation.

Glacier lake outburst prevention	Artificial lowering of glacial lakes	The process of draining water from glacial lakes vulnerable to overflowing by digging a canal from the lake to a nearby river. Drainage reduces water level and decreases pressure on moraine dams. This in turn reduces the risk of burst events.	<u>Download</u>
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4.4 WATER POLLUTION

The changing climate is affecting the entire global hydrological cycle, and increasing temperatures have a direct link to water quality. In addition to temperature increases, drivers of water quality degradation include the increasing frequency of floods and droughts and the impacts of human activity. Human activity remains the main cause of degradation. Many forms of water pollution will be exacerbated as a result of rising temperatures and precipitation intensity. This will affect water quality through greater pollutant (e.g. pathogens and pesticides) transport to freshwater bodies, and increased erosion, which in turn can potentially increase absorbed pollutants such as phosphorus and absorbed heavy metals. In semi-arid and arid areas, increased evapotranspiration resulting from climate change will increase the salinization risks for shallow aquifers (Bates, et al. 2008).

Additional climate-related factors affecting water quality that have been observed in recent decades include increased air temperatures and the subsequent warming of lakes and rivers. Combined with human impacts, this warming changes the internal hydrodynamics of water bodies, which affects species composition and nutrient and other pollution impacts. Rising temperatures also affect the chemical processes and properties of water, likely lowering its quality in standing bodies such as lakes due to increases in thermal stability and reductions in oxygen concentrations. This can lead to increases in eutrophication and algal blooms (IPCC 2014).

This section focuses on specific adaptation responses and technologies for mitigation of risks related to water pollution, addressing both climate change induced water quality concerns and the impacts of human activities. Both underpin the necessity of sustaining water quality to ensure existing resources are used productively in a changing climate, thus linking directly to the challenges of water scarcity and extreme weather events.

Nutrient pollution from agricultural activities is a current water resources management problem and one of the principal threats to water quality and freshwater ecosystems health. Higher intensity rainfall resulting from climate change can contribute to increased nutrient leakage and consequently eutrophication of water bodies. Improved land management and agricultural practices can mitigate these risks by **limiting nutrient leakage**.

Sea level rise, combined with increasing abstractions of groundwater in coastal areas, increase saltwater intrusion risks in aquifers, as well as water salinization risks (Bates, et al. 2008). Adaptation technologies for limiting saltwater intrusion can be found in chapter 4.5.

The increased frequency of extreme weather events such as floods and droughts is an important contributor to water pollution. The increased intensity of rainfall and consequent flooding increases the risks of combined sewer overflows (CSOs), flushing pollutants from the sewers into nearby water bodies and water sources (more on flood mitigation technologies can be found chapter 4.3). Similarly, during dry spells and drought, over-abstraction from aquifers can cause salinization and water quality degradation. Surface water quality is also affected by the increasing air temperatures, with potential for thermal pollution.

While climate change is likely to exacerbate many issues related to water quality loss, the primary cause of degradation remains unsustainable human activity. Lack of proper water treatment, population growth pressures and limited capacities of treatment systems must be addressed in parallel to climate change mitigation efforts. A number of treatment and pollution prevention technologies for **mitigating pollution at the source, flood proofing for water quality and improved water treatment capacity** are therefore also included in this chapter.

TABLE 4
Adaptation technologies for water pollution.

WATER POLLUTION			
Adaptation response	Technologies	Description	Technology description brief
Limiting nutrient leakage	Riparian buffers (e.g. wetlands, buffer strips)	Strips of vegetation along the banks of waterways (lakes, rivers, streams, etc.) that protect the water from potential pollutants from the surrounding land area, such as those from agricultural land and activities. The buffers are predominately forested with native trees, but can also contain smaller native bushes and shrubs.	Download
	Protected areas and land use limitations	Land use limitations and establishment of environmentally protected areas are legislative approaches to help meet water quality objectives and reduce waterway pollution due to nutrient leakage, for example nitrogen and phosphorous stemming from fertilizer use. Typically target agricultural activities and may require fertilizer use reduction to a specific limit, a pesticide use ban and establishment of fringe zones along watersheds where no agriculture is permitted.	Download
	Change in agricultural practices (limiting fertiliser application, sediment control)	Changes in land use practices can be implemented to reduce this leakage, particularly nitrogen and phosphorous, and the resulting nutrient pollution of waterways. Changes to more sustainable land use-practices aim to increase the ability of soils to retain nutrients, limit the amount of excess nutrients added to soils and minimize soil-loss from erosion. Improving farmer knowledge on soils and plants is also important for accurate dosage, timing and placement of nutrients to match the exact needs of the crop and avoid excess dosages, and therefore leakage.	Download
Limiting saltwater intrusion	<i>See section 4.5 on Sea Level Rise</i>		
Mitigating pollution at source	Source water protection¹³	Entails management and policy measures that restrict overuse and pollution of water at its source, and may include regulations (e.g. water allocation quotas, water quality compliance regulations), compensation schemes (e.g. payments to industrial or agricultural users to reduce use of pollutants or extraction volumes, payments for ecosystem services schemes) or conservation measures in the upstream watershed.	Download
	Water safety plans	A risk management tool to ensure a safe drinking water supply for human consumption. Effective safety plans require a holistic approach to water management where all possible threats to drinking water quality in the supply chain, from catchment/supplier to consumer, are assessed and interventions to control contamination risks are enacted.	Download
Flood proofing for water quality	Improved storm water management	See chapter 4.3 for more technologies on storm water management	
	Flood-proof wells	Specialized construction design and planning procedures to protect wells against the risks of flooding, and consequent water contamination. Specific measures include sealing wells with a protective cap (such as concrete or clay) extending several metres below the surface to provide a protective barrier for the upper part of the well.	Download
	Flood-proof sanitary latrines	Improved construction design and planning of latrines minimizes water contamination and health risks. Measures include elevating latrines or lining latrine pits to reduce waste infiltration and increase stability.	Download

¹³ Also included in chapter Too little water, as this technology has relevance for water augmentation.

Improved water treatment capacity	Advanced domestic wastewater treatment tanks	Advanced domestic wastewater treatment tanks are used to remove solids, pathogens and other impurities to meet water quality requirements. The treated water (effluent) becomes surface water, but can also be reclaimed for domestic uses such as toilet flushing and irrigation, or returned to groundwater sources.	<u>Download</u>
	Constructed wetlands for water treatment	Constructed wetlands make use of the natural purification processes of vegetation, soils and microbes to remove contaminants from discharge. Uses of constructed wetlands for water purification include applications in industrial wastewater and municipal wastewater and storm water treatment.	<u>Download</u>
	Improved efficiency of centralized water treatment systems	Improved efficiency of centralized wastewater treatment plants (WWTPs) includes technologies and procedures that treat larger capacities of water, requiring less energy and chemical inputs, while improving its quality. System optimization could include automated systems linked to sensors, or installation of new equipment (pipes, tanks, pumps, filters, etc.) to prevent leakages or inefficient treatment. Staff training and capacity building for better system operation can also be part of such efforts.	<u>Download</u>
	Improved point-of-use water treatment	Treating water at the point-of-use (such as the household) in places where centralized water treatment systems are not efficient or present. Low-cost and effective point-of-use treatment options include physical filtration (e.g. using cloths, ceramics, sand or specialized filters), chlorination or disinfectant powders (a chlorine solution or disinfectant added to water, killing most bacteria and viruses), solar disinfection (water bottled in clear plastic and placed under direct sunlight – ultraviolet rays and heat kill pathogens in still water) and boiling (heat inactivates dangerous bacteria and viruses).	<u>Download</u>

4.5 SEA LEVEL RISE

Coastal communities are at particular risk from climate change due to sea level rise, storm surges and other extreme weather events. Furthermore, changes in ocean temperature and chemistry will impact healthy coastal ecosystems and have wider effects on ecosystem services. Combined, these effects lead to a broad presence of hazards in coastal areas, posing a threat to human activities. The hazards have very different characteristics, temporal occurrence and impacts, but can be grouped into a number of key categories, including ecosystem disruption, gradual inundation, saltwater intrusion, erosion and flooding (Rosendahl Appelquist, L. et al. (2017).

More than one billion people currently live in coastal areas, and coasts are home to some of the most populated and economically significant cities in the world. Coastal populations are growing rapidly and could increase to between 1.8 and 5.2 billion by 2080, depending on population growth and coastal migration (IPCC, 2007). Larger populations and greater private assets and infrastructure will be increasingly exposed to coastal hazards in the coming years.

Adaptation technologies are critical for addressing coastal hazards and for meeting multiple management objectives. Different technologies can be used for addressing one or more hazards and have different efficiency, temporal coverage, flexibility and costs. This section provides a brief overview of these questions

to help coastal decision makers quickly identify and evaluate relevant technologies.

Whereas saltwater intrusion technologies mainly address saltwater intrusion hazards, the remaining categories address multiple hazards simultaneously. This opens up opportunities for co-benefits, as some of the options, particularly built infrastructure, can also have negative effects in regards to addressing hazards and on the broader coastal environment.

Saltwater intrusion is a process, which occurs in most coastal aquifers. Under natural conditions, the freshwater-seawater interface remains close to the coast as freshwater moves towards the sea. The natural balance between freshwater and saltwater in coastal aquifers is often disturbed by groundwater withdrawals and other human activities that lower groundwater levels, reduce fresh groundwater flow to coastal waters, and ultimately cause saltwater to intrude coastal aquifers. **Limiting saltwater intrusion** addresses the changing climate through technologies that limit salty seawater penetration in coastal surface waters and groundwater aquifers. Although groundwater pumping most often is the primary cause of saltwater intrusion, the lowering of the water table by drainage canals can contribute to saltwater intrusion. Other hydraulic stresses that reduce freshwater flow in coastal aquifers, such as lowered rates of groundwater recharge due to altered land uses in catchments affecting runoff or in sewered or urbanized areas, also can lead to saltwater intrusion (Barlow 2003).

While anthropogenic activities, such as over pumping and excess paving in urbanized areas, are the major causes of saltwater intrusion, it is anticipated that increases in the sea level due to climate change would aggravate the problem. Limiting saltwater intrusion in coastal areas is a critical adaptation response for ensuring a sustainable freshwater supply for public use and agriculture and horticulture, as well as for preventing damage to freshwater or brackish ecosystems. Addressing saltwater intrusion effectively through management interventions relies on in-depth localized understanding of coastal freshwater resources. To assess the threat of saltwater intrusion and to determine efficiency of management interventions, monitoring of coastal freshwater resources can therefore also be required.

Built infrastructure for shoreline protection constitutes adaptation technologies that use engineering to protect the shoreline. These technologies are often used for managing erosion and flooding hazards, especially in areas with high population densities, valuable assets and coastline infrastructure that requires long-term upkeep. If constructed properly, this infrastructure can be very durable and provide a high degree of security and value for coastal residents. However, it often has significant impacts on coastal dynamics, influencing the natural environment and ecosystems and the coastline's associated recreational value. These adaptation technologies can therefore be considered very effective for specific coastal protection purposes, but many come with a cost to the natural environment.

Green infrastructure for shoreline protection is an alternative to built infrastructure. It can be used for some of the same objectives, such as erosion and flood control, while also maintaining the coast's appearance and natural processes. It often requires flexibility from a planning perspective, but it can have

a range of co-benefits and facilitate repetition of the adaptation strategy over time. Its effects can also be enhanced if used in concert with built infrastructure. Green infrastructure is increasingly gaining attention worldwide as an accepted adaptation option.

Accommodation and management includes approaches for addressing coastal hazards by revising and reorganizing human activities in the coastal zone, or even at the river basin level. They therefore do not actively address certain hazards, and instead alter human activities through proactive planning to decrease negative impacts. By answering large-scale coastal challenges through coastal zoning and fluvial sediment management, the full range of hazards can be addressed with a longer-term perspective. This may also reduce the need for certain direct coastal protection measures. These options, together with certain green infrastructure approaches, are often called «building with nature», which aims to make natural coastal dynamics and human activities mutually beneficial, as opposed to more conventional protection approaches.

An overview of adaptation responses and related adaptation technologies is provided in the table 5 below and is followed by more detailed descriptions in the technology briefs. It is important to note that many of the adaptation technologies can be implemented together as part of an adaptation portfolio, and in many cases this will lead to the most optimal management strategy.

TABLE 5
Adaptation technologies for Sea level rise.

SEA LEVEL RISE			
Adaptation response	Technologies	Description	Technology description brief
Limiting saltwater intrusion	Limiting abstraction from shallow aquifers	Means of reducing abstraction of freshwater to sustainable levels through improved ground water management. It may include scientific monitoring and scientific assessments, improvements in water use efficiency/ regulations, improved and coordinated well operation and exploration of alternative water sources.	Download
	Barriers to fluvial saltwater intrusion	Establishment of physical or hydraulic barriers to hinder saltwater intrusion. Physical barriers constructed parallel to the coast consisting of a low-permeable material (such as steel or concrete) that acts to block the intrusion of saltwater into the aquifer. Hydraulic barriers consist of injecting freshwater and/or pumping saltwater to prevent the landward movement of the saltwater-freshwater interface.	Download

Limiting saltwater intrusion	Increasing sustainable aquifer recharge	Adding water to an aquifer through man-made systems (e.g., recharge basins or check dams, injection wells) to increase the amount of freshwater and to control or prevent the intrusion of saltwater. Water is often stored at the surface in a permeable man-made basin, which allows water to percolate down through the ground into the aquifer.	Download
	Coastal groundwater level monitoring	Monitoring approaches and associated data infrastructure to establish an in-depth understanding of the hydraulic processes that lead to salinity intrusion in coastal areas.	Download
	Coastal surface water monitoring	Monitoring approaches and associated data infrastructure to establish to inform of the hydraulic processes that lead to salinity intrusion in coastal areas, focusing on the interactions with surface water.	Download
Built infrastructure for shoreline protection	Revetments	Sloping shore-parallel structures constructed landward of the beach to dissipate and reduce wave action at the boundary between the sea and land. Typically protect a soft landform such as a dune area or coastal slope, or provide supplementary protection to existing defences such as a dike or sea wall.	Download
	Sea walls	Solid engineered structures with the primary function of protecting shoreline. Built parallel to the shore and aim to hold or prevent sliding of the soil, while providing protection from wave action. Although primary function usually is erosion reduction, they have a secondary function as coastal flood defences.	Download
	Land claim	Land claim creates new land from areas that were previously below high tide. Land claim can be considered an aggressive form of coastal protection that may more accurately be termed 'attack' or 'advance the line' according to shoreline management typology. It is usually undertaken to gain land for agricultural or development purposes, and is particularly common in coastal mega cities.	Download
	Beach nourishment	Primarily used to address coastal erosion, but it can also result in flood reduction benefits. A (soft) engineering approach that involves addition of suitable quality sediment to a beach area that has a sediment deficit. The addition rebuilds and maintains the beach at a width that helps provide storm protection.	Download
	Storm surge barriers/closure dams	Hard engineered structures with the primary function of preventing coastal flooding. Their secondary role is to shorten the required length of defences behind the barrier. Storm surge barriers are movable or fixed barriers or gates that are closed to prevent flooding when an extreme water level is forecast. Closure dams are fixed structures that permanently close off a river mouth or estuary.	Download
	Breakwaters	Shore-parallel structures located just offshore of the surf zone. They are designed to intercept and reduce incoming wave energy at the shoreline. They thereby protect the coastline behind breakwaters and encourage sediment accumulation, resulting in beach widening. Breakwaters are generally very solid, durable structures and are considered a hard-engineering protection measure.	Download
	Dikes	The primary function of dikes is to protect low-lying, coastal areas from sea inundation under extreme conditions. Dikes have a high volume that helps to resist water pressure, sloping sides to reduce wave loadings, and crest at heights sufficient to prevent overtopping by floodwaters. Dikes are made predominantly from earth, and consist of a sand core, watertight outer protection layer, protection and a drainage channel.	Download
	Groynes	Narrow, shore-perpendicular hard structures designed to interrupt longshore sediment transport by trapping a portion of the sediment that would otherwise be transported alongshore. By doing so, groynes help to build and stabilize the beach environment. Groynes are generally solid, durable structures and are considered a hard-engineering protection measure.	Download
	Jetties (inlet structures)	Hard structures built at the banks of tidal inlets and river mouths to trap longshore sediment, thereby stabilizing the inlet or river mouth and preventing channel siltation. Jetties are solid and durable and are considered a hard-engineering protection measure.	Download

Green infrastructure for shoreline protection	Artificial reefs	An artificial reef is a submerged (or partly exposed to tides) structure deliberately placed on the seabed to mimic functions of a natural reef, such as protecting, regenerating, concentrating and/or enhancing populations of living marine resources. This includes the protection and regeneration of habitats. Many reefs are built using objects that were built for other purposes, for example by sinking oilrigs (through the Rigs-to-Reefs program), scuttling ships, or by deploying rubble or construction debris. Other artificial reefs are purpose built from PVC or concrete.	<u>Download</u>
	Restoration and protection of coral and oyster reefs	Reefs are underwater ecosystems formed as a ridge of sand, rock or coral that rise up close to the water surface. Coral reefs are highly productive ecosystems held together by calcium-carbonate structures that are secreted by the corals. Oyster reefs are large communities of oysters that form on stony substrates. Reefs can be protected through legal means and monitoring, which minimizes potential threats. Restoration efforts include structural restoration, such as ship sinking or large rock relocation to expand coral habitat range, and biological restoration, such as culturing coral larvae or oysters, or collecting and rehabilitating broken coral pieces to assist growth.	<u>Download</u>
	Cliff stabilization	Measures carried out to minimize erosion of sloping soft rock coasts. Measures may take a wide variety of forms, including foot traffic protection, re-grading, smoothing, increasing vegetative cover and improving drainage. It can be implemented alongside various soft and hard coastal management measures.	<u>Download</u>
	Sea grass beds	Seagrasses are submerged marine flowering plants forming extensive meadows in many shallow coastal waters worldwide. The leafy shoots of these highly productive plants provide food and shelter for many animals (including commercially important species, e.g. prawns), and their roots and rhizomes are important for oxygenating and stabilising bottom sediments and preventing erosion.	<u>Download</u>
	Coastal wetlands (including mangroves)	Coastal wetlands include both freshwater and saltwater ecosystems that are situated in coastal watersheds where the water drains into the ocean. Sustaining climate adaptation functions (coastal storm protection, mitigation effects of sea level rise, erosion) requires conservation or restoration of coastal wetlands. Common interventions include replanting vegetation, sediment trapping and hydrological restoration.	<u>Download</u>
	Dune construction and rehabilitation	Natural dune rehabilitation refers to restoring degraded natural or artificial dunes to optimize coastal protection benefits. Artificial dune construction and dune rehabilitation are technologies aimed at reducing both coastal erosion and flooding in adjacent coastal lowlands.	<u>Download</u>
Accommodation and management	Coastal zoning	The division of coastal areas into zones that can be assigned different purposes and user restrictions. It allows multiple users to benefit from a coastal area under a broader sustainable management strategy. In a specific zone, certain activities can be allowed, allowed with permission, or forbidden, and the zoning can be geared to a range of different conditions, such as economic development, tourism, conservation and hazard presence.	<u>Download</u>
	Floating agricultural systems	Floating agriculture is a way of producing food in areas that are waterlogged for long periods of time. It is mainly aimed at adapting to increased or prolonged flooding. The system employs beds of rotting vegetation that act as compost for crop growth. The beds are able to float on the surface of the water, thus creating areas for agricultural use in a waterlogged area.	<u>Download</u>
	Flood proofing	The primary objective of flood proofing is to reduce or avoid the impacts of coastal flooding on structures. This may include elevating them above the flood plain, employing designs and building materials that make them more resilient to flood damage, and preventing floodwaters from entering them in the flood zone, amongst other measures.	<u>Download</u>
	Managed coastal realignment	The process of deliberately altering flood defences to allow flooding of a defended area. Managing this process helps to avoid uncertain outcomes and negative impacts. Generally involves setting back a line of actively maintained defences to a new line, inland of the original, or preferably to rising ground.	<u>Download</u>

Accommodation and management	Coastal setbacks	A prescribed distance to a coastal feature, such as a line of permanent vegetation, within which all or certain types of development are prohibited. A setback may dictate a minimum distance from the shoreline for new buildings or infrastructure facilities, or may require a minimum elevation above sea level for development. Elevation setbacks are used to adapt to coastal flooding, while lateral setbacks address coastal erosion.	Download
	Fluvial sediment management	A holistic management of sediment supply from rivers to the coast, taking the full range of human activities at the river basin into account.	Download

4.6 DISASTER PREPAREDNESS

Hydrological disasters represent the largest share of natural disasters worldwide today, causing thousands of deaths, and billions of dollars in economic damage annually. Floods affect more people worldwide than any other hazard (UNISDR 2015). Climate change is expected to exacerbate these losses, due to rising sea level, increased flood and drought frequency and coastal storm surges, in addition to risks related to glacial lake bursts.

Natural disaster impacts are often the hardest in middle to low income countries that have low adaptive capacity. It is particularly relevant to consider adaptation technologies in these settings, as natural disasters contribute not only to immediate disruption and damage, but also significantly delay achievement of fundamental sustainable development targets (UNISDR 2015). The disruptions created by hydrological disasters in many instances affect key infrastructure such as power production facilities, schools and medical facilities. Recovery in the aftermath of these events is hard for the most vulnerable groups in a society, who often do not have the means to rebuild after livelihood and property loss. Additional challenges include rapid urbanization and population growth, which increase the density of people and property exposed to disasters, as well as the degradation of natural ecosystems and their services that provide disaster protection.

A wide range of climate change adaptation technologies for mitigating flood, drought and coastal zone disaster impacts has been described in previous sections of this guide. In many cases, however, these adaptive measures can only limit the extent and mitigate the severity of disaster impacts, not prevent the event altogether. Therefore it is paramount that even with these measures in place, appropriate adaptation technologies for disaster preparedness to evacuate people and protect key infrastructure are established.

This final section of the adaptation technologies focuses on two types of disaster preparedness responses that can help ensure adequate preparation and evacuation in the face of imminent disaster, and thus prevent human casualties and mitigate infrastructure damage.

Early warning provides crucial information to responsible institutions about an approaching disaster, enabling them to warn at-risk communities and initiate disaster response operations. Reliable early warning systems play a key role in preventing human casualties as they provide timely disaster warning and lead to evacuation in exposed communities. The systems typically include ongoing weather event monitoring and disaster risk evaluation, as well as forecasting of developments that may create risks (UNISDR 2015).

Implementing **disaster response** technologies in turn can facilitate timely evacuation and ensure that exposed communities understand and follow evacuation procedures in the event of a natural disaster. On the national level, it is also crucial that the incumbent institutions are well-coordinated and their respective responsibilities in the event of a disaster are clearly divided and understood.

Table 6 below summarizes adaptation technologies with relevance to disaster preparedness.

TABLE 6
Adaptation technologies for Disaster preparedness.

DISASTER PREPAREDNESS			
Adaptation response	Technologies	Description	Technology description brief
Early warning	Flood forecasting systems	Flood forecasting systems help forecast potential flooding events before they occur. Forecasts increase lead-time for the public to prepare and evacuate, and helps provide an adequate response to minimize flood damage. The forecasting systems estimate expected water level rise using data inputs from simulation tools and models that predict precipitation levels and stream flow, as well as from hydrometric stations measuring water levels at selected points along a river or other water body.	<u>Download</u>
	Drought forecasting systems	Drought forecasting systems use models fed by climatic and atmospheric data (historical/seasonal weather patterns, real-time meteorological monitoring, and weather forecasts) to predict the probability of a drought occurring in a region or area of interest in the future (up to approximately three months). Drought forecasting systems are an important part of early warning systems, as they provide lead-time to planners for threat responses, which helps minimize drought impact risk.	<u>Download</u>
	Early warning systems for floods	The main purpose of early warning systems is to issue warnings when a flood is imminent or already occurring. As part of the warning, the system provides a prediction of the scale, timing, location and likely damages of the impending flood. The system uses data from sensors to measure water levels at strategic points in local water basins (rivers, lakes) or flood defences (dikes, dams, embankments) to forecast a potential flood event.	<u>Download</u>
	Landslide and mudflow warning systems	Systems that produce a warning when there is danger of a landslide or mudflow event in an area, improving disaster preparedness and minimizing event risks. The systems receive either real-time or periodic monitoring data from rain gauges and slope-movement sensors on site. The data is coupled with data from mathematic models calibrated with local topography, geo-physical characteristics, land use and forecasted meteorological data to determine the risk of a landslide or a mudflow.	<u>Download</u>
	Decentralized community run early warning systems	Low-cost technology for improving disaster preparedness run by local community members. The community members use simple equipment to forecast potential natural disasters such as floods, landslides and drought, and operate a communication/dissemination system to inform other local residents of impending threats.	<u>Download</u>
	Drought early warning systems	A drought early warning system's main purpose is to warn local communities when there is risk of a drought, improving preparedness and decreasing risks associated with crop and food loss. Effective warning systems require drought monitoring using appropriate drought indicators, meteorological data and forecasts, a warning signal, public awareness and education, institutional cooperation, and data sharing arrangements. An early warning system combined with the slow onset of a drought can give sufficient lead-time to local decision makers to mitigate drought threats, for example by arranging for emergency food supply, planning water harvesting programmes or introducing improved dry-land farming initiatives.	<u>Download</u>
	Flash flood guidance systems	Specialized forecasting and early-warning systems for flash floods. Flash flood guidance systems are designed to provide forecasters with data that allows them to predict a potential flash flood (usually a few hours before it hits), and produce an early warning to increase preparedness.	<u>Download</u>
	Real-time monitoring networks	Systems of sensors and radars, and the accompanying computer systems, to track changes in hydrological conditions in near real-time. Real-time monitoring provides an important source of information for early warning systems and timely flood preparedness. Remote sensing data on measures such as rainfall, wind, water levels and slope movement send information to a server immediately after data collection, thus increasing lead-time before a potential natural disaster such as flooding or landslides.	<u>Download</u>

Disaster response	Stacking of sandbags combined with the use of ground improvement technology (for basic restoration and reinforcement/restoration)	Sand-filled cloth bags are stacked to create stable structures that can hold back water and sediment flow during flooding or storm events. Sandbag barriers are temporary blockades that protect buildings and populations from inundation damage and associated economic loss. Sand bag stacking procedures can additionally be combined with simple and low cost techniques to reinforce the ground, further strengthening the defence.	<u>Download</u>
	Flood Disaster Preparedness Indices (FDPI)	Used to assess the preparedness of a local community to tackle flood situations. FDPI is made up of eight indices, each affiliated to a different aspect of flood disaster preparedness. The indices are: state of infrastructure, mitigation plans, mitigation systems, evacuation plans, recovery plans, information and education, collaboration, and community strength. They are based on self-assessment, replying to a number of questions related to each aspect.	<u>Download</u>
	Communication protocols	Communication protocols for disaster response lay out a framework for communication tools and the specific responsibilities of various institutions, in the time of disaster.	<u>Download</u>
	Flood shelters	Strong elevated structures that can be used by local residents for refuge during an extreme weather event.	<u>Download</u>
	Social media applications for disaster response and mapping	Uses social media applications to disseminate information during or following a disaster, and allows for those affected by a disaster to be in touch with disaster relief organizations, friends and family. Information transmitted via these applications can also be used by emergency teams to determine the scale of the disaster and pinpoint specific locations in affected areas. It can also be used to quickly notify a large number of people about distribution sites, shelter areas, evacuation zones, etc.	<u>Download</u>
	National and community disaster management plans	Plans created to improve disaster risk management governance from the state to local level. National disaster management plans incorporate disaster risk management into national policies and establish a framework that clearly specifies the roles of the responsible institutions/committees. Disaster management plans at the community level can be fine-tuned according to prevalent area risks, allowing for a more specific and detailed plan tailored to local circumstances.	<u>Download</u>

5. PRIORITIZING AND SELECTING ADAPTATION TECHNOLOGIES

5.1 INTRODUCTION TO PRIORITIZATION OF ADAPTATION TECHNOLOGIES

For every climate related water challenge, there is a broad range of potential adaptation responses available. The previous chapter of this guide introduced a menu of technologies for adaptation to different climate stressors in the water sector. The task of decision makers, practitioners, managers, technology adopters and other stakeholders is to contribute to the evaluation of these technologies so that the most appropriate intervention (or portfolio of interventions) is chosen for a specific climate related water challenge. The evaluation is typically based on a number of considerations, such as the specific water challenge, technological feasibility of the intervention, suitability of the technology for a specific socio-economic context, and resources at hand. This can be a daunting task amidst the complexity of water interactions across a number of sectors, as well as the wide spectrum of users and stakeholders that rely on water and water ecosystem services. Reconciling these diverse needs while ensuring the adaptation technology addresses the actual water challenge requires robust approaches to evaluating and prioritizing the adaptation technology options.

In this context, a prioritization process enables a decision maker to select a technology (or a set of technologies) for implementation. The process entails identifying criteria for assessment, followed by evaluating the performance of technologies using these criteria. The best performing technology, or set of technologies, in all the chosen criteria (or at an aggregate level) is selected for implementation. Robust and well thought through criteria, and the weight given to each criterion according to its importance in the set is key for prioritizing technologies. However, the process for establishing the criteria, and their respective weights, is equally important.

Water's importance for the social, economic and environmental well-being of a community, geographic region or any other system makes it important to engage stakeholders from different fields related to the technology and the sector, as well as from the different stages of technology dissemination. For example, key stakeholders for water conservation and sustainable use technologies for small-scale rural agriculturists

can include researchers and technology developers, those who are a part of the market chain like suppliers of ancillary products, distributors, financial players and end users. Box 2 provides a brief overview of the stakeholder engagement process and the ways in which they can contribute to the technology prioritization process. Bringing together key stakeholders, such as those that are relying on water resources or are being impacted by the climate change, is one way to ensure that the technology choice is appropriate for a given context and increases benefits. In addition, stakeholder engagement in certain cases can support local ownership and buy-in, which is often crucial for long-term sustainability of adaptation projects. Stakeholder engagement can also support identification of locally relevant criteria for technology prioritization. Box 2 briefly describes the process that stakeholders can follow to determine priorities for implementation.

This chapter will provide a brief account of the general prioritisation process steps when using technologies for adaptation. Further sections include a list of commonly used methods for technology prioritization and selection. The final section provides an overview of ways that water adaptation technologies can be mainstreamed at the national level to ensure due recognition within national priorities and policy frameworks.

Box 2 : Engaging Stakeholders

Depending on the prioritization process being followed, stakeholders will need to be engaged at the different assessment levels. Engagement with stakeholders may involve following steps :

- First, identification of the prioritization process and the steps to be followed in process ;
- Second, identification of every step at which engagement is needed ; and
- Third, identification of the right set of stakeholders based on the tasks involved

Those facilitating the engagement process should ensure that stakeholders are clear about their role, process objectives and expected outcomes. For example, a manufacturer, financing expert, end user and local civic representative can all provide inputs on the costs of technology. Other tasks that can involve stakeholders, include identification of a larger pool of technologies, appraisal mechanisms and criteria selection.

Based on the nature of task, different sets of stakeholders may be involved. For example, to identify a larger pool of technology options, technology and innovation experts are needed in the stakeholder group. Similarly, when identifying criteria for prioritization, a more balanced stakeholder group comprising policy makers, user representatives, producers, technical experts, NGOs, research organizations and similar groups is needed. This becomes vital when the scale of implementation (and subsequently the amount of resources) is large. Large-scale implementation also potentially affects different socio-economic strata of people and different geographic regions that would need representation in stakeholder consultations. On the other hand, smaller scale implementation and local projects may also require wider representation than just local experts in the stakeholder group. Often capacity at the sub-national level, particularly at the community level, can be low. These capacity gaps have to be kept in mind while selecting stakeholders.

Identifying the interest and potential impact of each selected stakeholder will help to better prioritise and confirm those that should be fully engaged in the project steps. Finally, the mode of engagement with stakeholders should also be determined, along with the process. For example, whether it should take place through direct interviews, public forums or focus group discussions.

Sources: *Libélula 2015 ; NEA 2015.*

Box 3: Steps in prioritization

Step 1 : The decision context

To identify a relevant set of prioritized technologies the first step is to determine the context within which the technology decision should take place. Decision contexts are generally the economic, environmental, social and political settings that surround the decision-making process. For example, reducing vulnerability to drought, enhancing resilience to floods and reducing impacts from salinity are environmental decision contexts; equitable water access is a social decision context; and affordability is an economic decision context. The decision context should be aligned with national policies and programmes. Along with identification of the decision context, the broader analysis objective(s) should be identified. These broader objectives can then have different components and targets. An example of a broad objective is 'to reduce crop vulnerability to prolonged droughts'.

Step 2: Identify options

There are many technology options to meet the decision context objectives. A menu of options helps stakeholders review each technology's potential to meet the decision context objectives. This guide provides one such menu of options for meeting various adaptation challenges in water sector.

Step 3: Evaluate options

This step entails, first, identifying the assessment criteria and second, evaluating each technology option's performance against these criteria. One way to identify criteria for evaluation is in a stakeholder setting (Box 2), where important criteria and their weights can be determined. For example, capital costs, technology lifespan and annual water savings are a few criteria against which a more efficient micro-irrigation technology can be assessed. Criteria weights determine their relative importance in decision-making. Multi criteria decision analyses (or similar such tools) can subsequently be used to assess overall technology performance. This step results in an ordinal set of priority technologies.

Step 4: Sensitivity check

Before shortlisting a prioritized pool of adaptation technologies, a final check should be made on their sensitivity to changes under key assumptions. For example, in a multi criteria assessment, it is important to check prioritized technologies' robustness against other chosen criteria or their weights. According to the Technology Needs Assessment (TNA) project¹, when divergent views are incorporated in a stakeholder setting, the prioritized pool of technologies does not significantly change. Though stakeholders may have strong views on certain criteria weights or technology performance, incorporating these divergent views just changes the technology's rank, and does not affect the final technology set. This step can therefore also support consensus building amongst stakeholders.

Sources : *Communities and Local Government 2009 ; Dhar, Desgain and Narkevičiūtė 2015 ; Haselip, Narkevičiūtė and Rogat 2015 ; Trærup and Bakkegaard 2015.*

** Details on TNA project available at tech-action.org*

5.2 EXISTING TOOLS FOR PRIORITIZATION

There are many tools available to prioritize technologies for adaptation, or to filter a relevant subset from a larger technology pool for implementation. This section lists some commonly used tools and approaches. The scale of implementation (for example, village, city, or regional level), information availability, and technology complexity are the key factors that determine which tools will be relevant for the prioritization process in a given context. For example, if the scale of implementation is limited to a small rural community, the pool of technologies to be prioritized may be small and there may not be a requirement for an extensive analysis. On the contrary, for a large-scale implementation (for example, in a one million plus urban agglomeration), the prioritization process may include more criteria for assessment, more information may be available to assess the technologies against each criterion, there may be more potential technology options, and there may be more than one water challenge to address.

Some of the methods listed below have their roots in project management activity prioritization. However, they can be adapted and are therefore relevant for prioritizing technologies for adaptation. These tools are available to support the decision-making process but should be carefully chosen or adapted to suit the context. A good assessment does not necessarily mean application of complex tools. The tool's suitability to the context and its effectiveness in identifying priority technologies should be the central concerns for its selection. Tool suitability also implies users understand its underlying assumptions. Users may include stakeholders that are involved in the prioritization process. In this case, ensuring process transparency, and clarity on tool assumptions, as well as prior planning for prioritization process execution, ensures that the outcome is relevant for meeting the decision context objectives.

Some common approaches for assessment, comparison and prioritization of various technologies for adaptation are further described below.

Cost Benefit Analysis

Fundamentally, a cost benefit analysis (CBA) looks into the enumeration and assessment of relevant costs and benefits for a project, technology application or programme, over a period of time to assess investment decisions (Drèze and Stern 1987) (Prest and Turvey 1965) (Sassone and Schaffer 1978). The cost benefit analysis draws its concepts from different branches

of economics, including welfare economics (Prest and Turvey 1965). The concept is rooted in the simple logic of objectively comparing costs and a 'time adjusted' revenue/benefits stream from a project. In the process, all costs involved are calculated and compared with the 'net present value (NPV)' of the expected revenue stream. If the benefits are greater than the costs, the project is deemed economically acceptable. This method can be used for studying one technology in detail or comparing technologies, policies or programmes focussed on technologies. In the context of prioritization of technologies, this tool can be used to narrow down a larger set of technologies to those with the highest net benefits.

There are many direct and indirect costs and benefits of technologies for adaptation. Those that are direct and tangible can be measured, or some assumptions can be made for estimating them. Those that are indirect and intangible can be difficult to value (Sassone and Schaffer 1978). For example, a large dam may help farmers with irrigation and reduce the impact of drought, which can be directly measured through a number of indicators such as production levels or increase in farm area under irrigation. However, the benefits, for example, of increased energy and food security, or increased political influence of those benefitting from the dam, are extended benefits that cannot be measured directly. Direct costs borne by the direct user may only be part of the total cost of implementing the technology.

In some cases, methods of contingent valuation, which is based on the concept of 'willingness to pay', can be used to assess intangible and affiliated benefits from technologies (Carson and Hanemann 2005). Methods of 'Value of a Statistical Life (VSL)', which is the amount of money a person (or society) is willing to spend to save a life, can be used for estimation of health benefits (Ashenfelter, 2005). These methods have many assumptions and have to be adapted depending upon the context for incorporating into the CBA.

When measuring only the tangible costs and benefits of technologies for adaptation in the water sector, the costs may turn out to be much higher than the benefits. The positive externalities of technologies for adaptation can reach beyond immediate users, and therefore the benefit assessment level needs to be determined, i.e. immediate, secondary and tertiary benefits, etc. It is important to assess these intangible benefits and non-monetized changes in welfare. For example, the Technology Needs Assessment in Kenya identified rainwater harvesting as a priority technology¹⁴. Its social and economic benefits can be classified as follows :

- Direct benefit : Enhanced availability of drinking water

¹⁴ Technology briefs can be accessed on <https://www.ctc-n.org/resources/climate-change-adaptation-technologies-water-practitioner-s-guide-adaptation-technologies>

for domestic and agricultural water for arid and semi-arid areas ;

- Second order benefit : Enhanced growth of social structures and women's empowerment.

Similarly, there can be third order benefits that result from second order benefits. In the higher order benefits, it may become difficult, for example, to identify what parts of enhanced growth of social structures and empowerment of women can be attributed to the technology implementation and what parts to additional factors such as local NGO efforts or institutional initiatives. Furthermore, it can also be difficult in implementation to assess how much benefits from one technology should outweigh benefits from another.

Projects spanning many years may also require some level of economic discounting to increase precision of the cost benefit analyses (Hanley and Spash 1993). Discounting entails choosing the right rate from the spectrum between an empirically based (finance-equivalent discount) rate and a social (the social welfare-equivalent discount) rate.

Using various sources and methods, climate projections, and expert involvement are all helpful approaches when verifying data to improve analysis robustness and work with estimates and uncertainties. Many of these complexities surrounding estimation can also be simplified by making plausible assumptions that involve stakeholders. For example, community partners may not be able to produce an exact assessment for indirect second order benefits. However, they can provide support by attributing a range to them. Similarly, stakeholders from public institutions can help identify the best options for a discount rate.

The CBA tool is still evolving and has come a long way from its initial use during the 19th century for water infrastructure projects in the United States (Mishan and Quah 2007) (Pearce 1998). With better estimation methods available in the future, CBA-based decisions will be more evidence based, particularly in the context of technologies for adaptation.

Multi Criteria Decision Analysis

Prioritizing technologies for adaptation is a complex process and goes beyond assessing only costs and revenue streams, which is why a 'multi criteria' approach is often used. Multi criteria decision analysis (MCDA) traditionally started as a discipline of operations research and currently is used regularly in financial portfolio management (Velasquez and Hester 2013). In financial portfolio management, the assessment focus is quantitative. In prioritization of water technologies for adaptation, MCDA combines the use of both quantitative and qualitative criteria such as social, environmental, technical, economic and financial

(ibid). With the technologies for adaptation MCDA , those technologies that excel in additional criteria (other than just the water challenge at hand) are also considered for implementation. For example, a small dam and rainwater harvesting are two technologies addressing the same water challenge. Using MCDA, the decision makers can assess these technologies' performance on additional criteria such as financial or environmental dimensions. Another example is assessing flood mitigation interventions. Whereas, both seawalls and mangroves may provide the desired level of protection against storm surges, the assessments could be supplemented with criteria on ecosystem services, economic benefits and performance.

The MCDA steps include :

- Establishing a decision context ;
- Identifying the performance criteria ;
- Rating the option's performance for each criterion ;
- Assigning weights ;
- Combining scores and weights ;
- Examining the results ;
- Conducting a sensitivity check (Dhar, Desgain and Narkevičiūtė 2015).

Engagement with stakeholders is essential to identify criteria for the assessment, their weights and subsequent valuation. The process requires participation and consensus from stakeholders, which can make it time and resource consuming. Depending on the context or available resources, the assessment could be quantitative or qualitative – an advantage for assessing technologies with high externalities (where supplementary qualitative assessments can be useful). Stakeholder values and priorities can be reflected by assigning weights to some criteria (for example, contribution to local livelihoods has more weight than annual generated returns). However, care must be taken to ensure that they are not ambiguous and that stakeholders are able to reach consensus on their value.

As they are based on designing a common metric for comparing and ranking options, both CBA and MCDA tools can be used to prioritize technologies. They both are sensitive to assumptions. The key difference is that CBA emphasizes monetizing future benefits and costs, while MCDA relies on measuring performance against each criterion (which could be quantitative or qualitative). MCDA allows for detailed assessment, though it can be rife with ambiguity.

Quadrant Method

The Quadrant Method supports classification of technologies into groups of high and low priorities. These grids are often used in different forms in management science and business strategies (Obolensky 2003). Technologies are classified in a

matrix with each axis representing a criterion. Generally, very broad criteria are selected for representing the axes. For example, one axis can represent relevance and the other can represent impact. The axes contain a scale of high to low for each criterion.

Figure 6 below uses two criteria – ease of implementation and need for a technology – scoring from low to high on each axis. The top right matrix, which is High need/High ease of implementation, is the highest priority quadrant. Technologies classified in this quadrant should be implemented first. Technologies that fall in the bottom left quadrant should not be prioritized. Technologies falling within the remaining two quadrants can be employed after the high priority technologies, based on available resources and ease of implementation. The two priority criteria could also have supplementary sub-criteria. For example, 'ease of implementation' can be supplemented with 'cost' and 'time period for implementation' as its sub-criteria. The aggregation of these is then represented in 'ease of implementation'. Adding further criteria, particularly those related to qualitative assessments, help technology assessment and prioritization to the benefit of local stakeholders. However, this also creates a need for stakeholder engagement throughout the prioritization process.

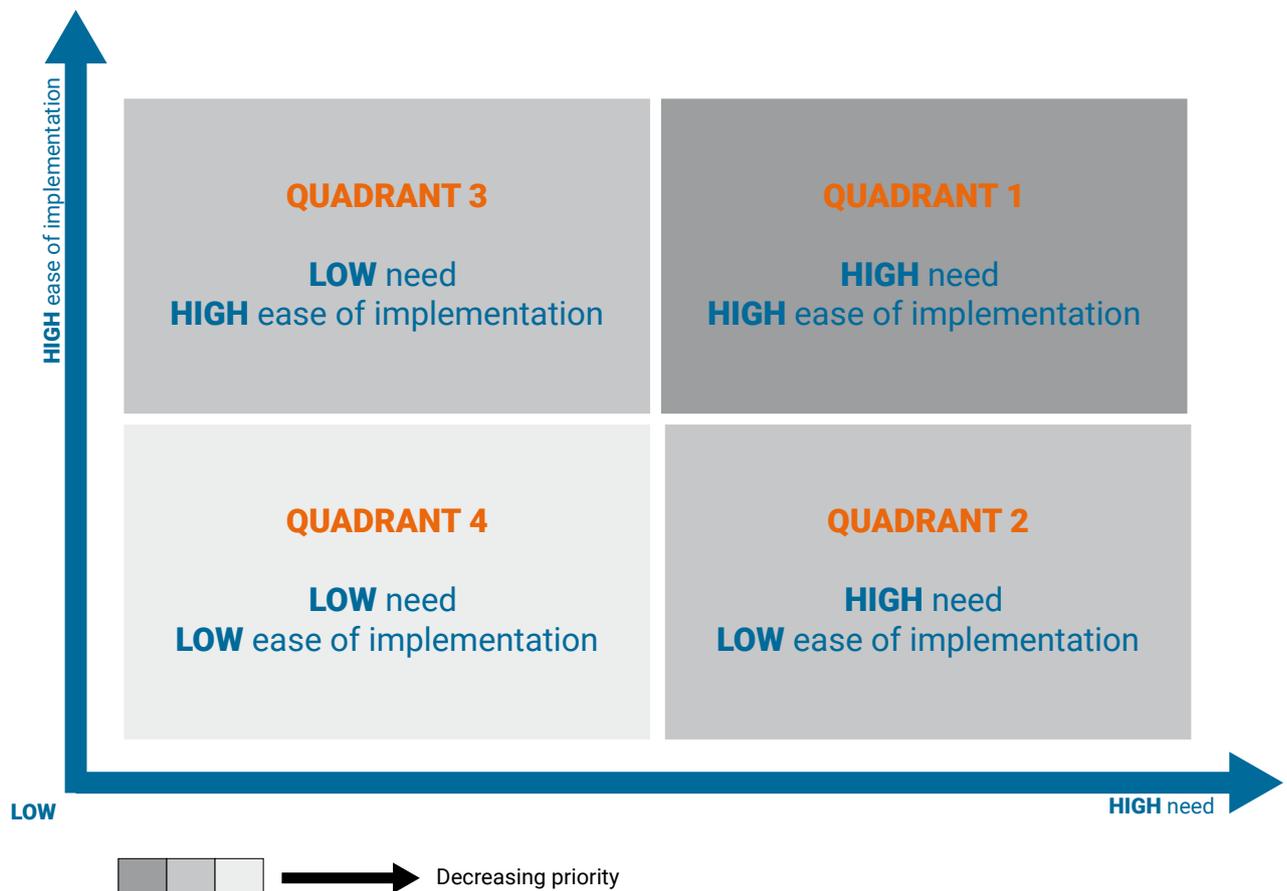
The advantage of this tool is that it can be pursued with limited resources. It is particularly relevant when the criteria for assessment are limited. If five or six simple comparable technologies have to be prioritized for implementation in a small rural community, it may not be necessary to pursue an elaborate MCDA exercise. In this case clustering is more relevant than absolute ranks for comparable technologies. This tool uses a simple approach, and the analysis is not as robust as that in CBA or MCDA. However, if implementing at a small scale with a small pool of comparable technologies, it can be efficient.

Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) draws from paired comparisons and MCDA for prioritization. This technique finds applications in prioritization, resource allocation, quality management and benchmarking (Saaty 1980). It involves:

- Setting an objective ;
- Determining assessment structures such as criteria, sub-criteria and alternatives under consideration ;
- Comparison in pairs of each of the criteria and sub-criteria ;
- Calculation of weights ;

FIGURE 6
Example of Quadrant Assessment.



- Evaluation to obtain a final ranking (Bozóki, et al. 2013).

The first two steps of defining an objective and identifying criteria for evaluation are common for most prioritization processes.

Pairwise comparisons are useful in determining relative weights of criteria. These can be based on actual measurements or opinions from a group of experts/ stakeholders. Experts and other stakeholders provide the data for criteria comparison through the Delphi Method¹⁵. The importance of each criterion is assessed against every other criterion and is arranged in a matrix as shown in Figure 7. The value 1 implies that both the criteria have equal importance. Value 3 (in C2 C1) implies that C2 is three times more important than C1. Value 2 (in C3, C1) implies that C3 is 2 times more important than C1.

A normalized principal eigen vector is calculated from the paired comparison matrix. The example here shows the weight of criteria C1, C2, and C3 is 17%, 43%, and 40% respectively. This calculation can be pursued further if sub-criteria are under consideration. This is followed by a consistency check through a consistency index (Saaty 1980). Finally, each of the ratings is multiplied by their determined weight to produce the prioritized list of technologies. This technique is quantitative and relies on expert judgement to determine the criteria and paired comparisons.

AHP and MCDA are often compared according to their strengths and weaknesses. Both MCDA and AHP can incorporate subjective and objective assessments. One distinct advantage that practitioners find in AHP is the breaking down of the decision context by building

criteria hierarchy. In addition, there is scope to measure the consistency of a decision maker's judgements (Macharis, et al. 2004). This tool can become tedious to use if the number of criteria and sub-criteria is large (Stefan and Higgins 2008). The scale does limit decision makers while building the criteria, and they may find it limiting to e.g. classify criteria from scale of 1-5 only.

5.3 RELEVANT CRITERIA FOR TECHNOLOGY SELECTION

The criteria and sub-criteria are the measures or parameters against which technology's performance is judged. The key question addressed by selected criteria supports decision makers to distinguish between a 'good' and 'bad' (or average) technology for adaptation choice. They facilitate comparison amongst alternatives in meeting climate change goals. Choice of criteria for assessment can be completely driven by stakeholders or based on already existing independent scientific criteria. The stakeholder group can be supported with framing conditions to define the objective and look into relevant policy literature and scientific documents to support their final criteria choice.

The chosen criteria should comprehensively measure the appropriateness of technologies to address adaptation challenges and deliver on specific adaptation goals (for example, amount of water saved) in the context of a specific case. Comprehensiveness also implies that criteria should be mutually independent, not redundant and not double count any aspect. The chosen criteria should be operable – there should be clarity on their measurement and execution – and have no ambiguities in their description. Apart

FIGURE 7
Paired comparison matrix.

	Criteria 1 (C1)	Criteria 2 (C2)	Criteria 3 (C3)
Criteria 1 (C1)	1	1/3	1/2
Criteria 2 (C2)	3	1	1
Criteria 3 (C3)	2	1	1

¹⁵ The Delphi method is a forecasting method that relies on structured communication through questionnaires where responses from experts are recorded anonymously and a facilitator helps the experts group come to a consensus.

from this, the number of criteria should be neither too many nor too few. More criteria make the assessment process more resource demanding, and potentially more complicated. Additional criteria should be included only if each new criterion adds incremental value to the assessment process. Finally, it should be ensured that application of the chosen criteria produces uniform outcomes irrespective of who implements it or if it is repeated.

If the criteria are broad they can have sub-criteria. For example, a 'social impact' criterion could have many sub-criteria, such as increase in income, improved water access, decrease in doctor visits, reduction in infant deaths resulting from inadequate access to water and sanitation, etc. The criteria can be measured either quantitatively or qualitatively, and the measurement process should be clear. For qualitative criteria, the decision maker should know the basis for ordinal arrangement of the technology options. Some

prioritization processes may benefit from assigning weights to the criteria. The stakeholder group making the selection should first come up with a long list of assessment criteria and their sub-criteria. This is followed by screening for comprehensiveness, double counting, redundancy and relevance to context to come up with a smaller pool for the assessment.

There are many potential criteria and sub-criteria for assessing technologies for adaptation in the water sector. Table 7 provides an example of two broad criteria groups of costs and benefits. These criteria are further divided into sub-criteria and measurement indicators. Table 8 provides specific examples of relevant indicators for technologies for adaptation in the water sector. Table 9 shows the prioritization criteria used by the Lebanon in Technology Needs assessment project. For each of these criteria there is a measurement scale and weight attached.

TABLE 7

Criteria list and example indicators.

Criteria	Sub-criteria	Indicators
Costs		<ul style="list-style-type: none"> • Capital costs • Operating costs • Maintenance costs • Institutional costs
Benefits	Institutional	<ul style="list-style-type: none"> • Ease of implementation • Alignment with national priorities
	Environmental	<ul style="list-style-type: none"> • Ecosystem protection • Quality and supply of water • Support to ecosystem services • Reduction in pollution • Reduction in GHG emissions
	Social	<ul style="list-style-type: none"> • Improved health • Reduced poverty • Preservation of natural heritage
	Economic	<ul style="list-style-type: none"> • Economic performance • Increase in income • Reduced unemployment • Increase in production

TABLE. 8

Shows an example of criteria, sub criteria, indicators and sources of information for the indicators¹⁶.

	Indicators	Sources of Information
Sub-criteria	CRITERION: COST	
Cost of set-up	<ul style="list-style-type: none"> • Capital cost per unit of technology • Import cost (Taxes) • Installation cost 	<ul style="list-style-type: none"> • Accounts from technology supplier • Technology specifications • Expert judgements • Secondary estimates
Cost of maintenance/ implementation	<ul style="list-style-type: none"> • Operating costs per unit time • Maintenance costs • Costs per unit of storage capacity • Costs for maintaining average annual/ critical month storage 	<ul style="list-style-type: none"> • Accounts from technology supplier • Technology specifications • Expert judgements • Secondary estimates
Other types of spending in absence of climate technology and/or to create an enabling framework	<ul style="list-style-type: none"> • Investments in water management infrastructure • Expenses to support water conflict resolution • Costs for managing and operating institutional arrangements • Costs for implementing water policy reform • Costs for additional monitoring and analysis of aquatic ecosystems 	<ul style="list-style-type: none"> • Public budgets in water management • Tax structure • Expert judgements • Secondary estimates
Sub-criteria	CRITERION: ENVIRONMENTAL PROTECTION	
Biodiversity protection	<ul style="list-style-type: none"> • Number of species • Area under protection • Number of conservation policies 	<ul style="list-style-type: none"> • Biodiversity monitoring data • Sample surveys
Protection of environmental resources	<ul style="list-style-type: none"> • Ground water quality and quantity • Surface water quality and quantity • Reduced degradation from runoff 	<ul style="list-style-type: none"> • Environmental monitoring data • Sample surveys
Support to ecosystem services	<ul style="list-style-type: none"> • Water quality and extent of purification • Ground /surface water quality and quantity 	<ul style="list-style-type: none"> • Remote sensing analysis • Qualitative judgements by experts • Sample surveys

¹⁶ Derived from MCA guidance on adaptation technologies (Trærup and Bakkegaard 2015)

TABLE 9*Lebanon : Water sector technology prioritization criteria for TNA.*

Criterion	Description	Scale	Weight
Capital and operational cost	This includes initial cost to establish the technology as well as the annual maintenance and operational costs. Some figures per surface or volume units are provided for some technologies. It highlights the ease of access farmers have to the technology.	Very low (5) Low (4) Medium (3) High (2) Very High (1)	High (1.5)
Extent of use	It assesses the extent to which the technology is applicable within the different geographical contexts, agro-ecological zones, and the number of targeted beneficiaries.	Very low (1) Low (2) Medium (3) High (4) Very High (5)	High (1.5)
Capacity to increase water efficient use	This highlights the ability of technology to improve efficient water use. The higher the values the more water is used efficiently.	Very low (1) Low (2) Medium (3) High (4) Very High (5)	High (1.5)
Capacity to increase water supply	This highlights the ability of the technology to improve water supply. The higher the values the higher the supply of water.	Very low (1) Low (2) Medium (3) High (4) Very High (5)	Standard (1)
Need for human resources and knowledge	This describes the technology's human requirements and needed qualifications. The higher the need for human resources and training, the lower the score.	Very low (5) Low (4) Medium (3) High (2) Very High (1)	Standard (1)
Need for infrastructure	This reflects the availability of needed infrastructure to deploy the technology. If infrastructure is absent, the score is lowest. If the infrastructure is simple, and available, the score is highest. It also highlights the time required to establish and disseminate the technology.	Very low (1) Low (2) Medium (3) High (4) Very High (5)	Standard (1)
Social acceptance	This reflects social acceptance at all levels: water users, farmers and decision makers.	Very low (1) Low (2) Medium (3) High (4) Very High (5)	Standard (1)
Negative environmental impact	If there is a negative impact of the technology on the environment, the score is low.	Very low (1) Low (2) Medium (3) High (4) Very High (5)	Standard (1)

5.4 Mainstreaming technologies for adaptation in the water sector¹⁷

There is little doubt on the relevance and benefits that technologies for adaptation in the water sector can accrue. About 142 countries included adaptation in their Intended Nationally Determined Contributions (INDCs) and many countries ranked the water sector as a priority sector where climate challenges need to be addressed. Other priority sectors such as agriculture, health and sanitation and industry are also dependent on water, underscoring the sector’s importance.

One way to meet climate challenges in water and dependent sector(s) is to mainstream technologies for adaptation at different levels into relevant policies, plans, programmes, and projects at the national, sub-national, and local levels (USAID 2009). Mainstreaming refers to individual implementation, including technologies for adaptation, as part of a broader suite of measures within existing development processes and decision cycles (OECD 2009). In this section, we look at mainstreaming from two aspects. First, incorporation of technologies for adaptation in the water sector within the national policies and planning framework of the country. This sets the overall objective and ambition of the country. Second, the adoption by end users, which shows the implementation or the change from a conventional to a more sustainable technology for adaptation (Olhoff and Schaer 2010). This is a top

down approach using mainstreaming at a policy level to bring about change in technology adoption. It seeks to mainstream efforts at a macro level, with subsequent implementation through programmes.

Mainstreaming at the national level can be done, amongst others : through incorporation of technology action plans in programme implementation, in policy formulation such as national visions and planning for multi-year/period development plans ; through resource allocation from national budgets or special purpose funds for addressing climate initiatives ; through capacity building ; and by recognizing climate change risks for the water sector in national communications, INDCs and other programmes.

Mainstreaming at the programme level is done through awareness raising, climate impact assessments and interventions specifically designed to manage risks. There are also community led efforts in mainstreaming, such as in micro-finance, that have supported technology adoption. Many countries have also participated in the Technology Needs Assessment (TNA) project, supported by The Global Environment Facility (GEF), to identify their technology priorities and subsequent implementation plans.

Private sector engagement through partnerships can be helpful in making technologies for adaptation viable by developing financial plans and prototypes.

FIGURE 8

Mainstreaming climate change adaptation action at different levels.



¹⁷ The two terms ‘mainstreaming climate change adaptation’ and ‘mainstreaming technologies for adaptation in the water sector’ are used interchangeably in this section. The points relevant for terms ‘mainstreaming climate change adaptation’ are also relevant for ‘mainstreaming technologies for adaptation in the water sector’. In practice the latter will be a subset of the former.

Private enterprises are often involved in investing and implementing market technologies¹⁸. Programme level mainstreaming focused on a specific geographic location can be effective in bringing about sustainable change at a grassroots level. Market mechanisms and the private sector have a pivotal role in mainstreaming technologies. However, the involvement can be challenging, as there are limited direct revenue flows for end users in technologies for adaptation. The beneficiaries may even fail to perceive the benefits from technologies. For example, green infrastructure for shoreline protection may have many benefits for the ecosystem, water quality and health. People living far from the coast, however, may not perceive these as benefits accrued to them.

National level mainstreaming ensures that decision-making at any level takes adaptive measures into consideration. Incorporation of adaptation initiatives also acknowledges the increased risk of adverse impacts from climate change. National ministries (like those for environment, finance, or planning), civil society and businesses can play important stakeholder roles to facilitate mainstreaming at the national level (OECD 2009). National visions, sustainable development strategies and strategic development plans can be relevant for mainstreaming at a national level. Mainstreaming at a programme level can be tied to specific programme activities. Typically, efforts at the programme level focus on a specific programme objective or sector. Sub-national governments, community-based organizations and non-governmental organizations are the key players (ibid). For example, UNFCCC (the United Nations Framework Convention on Climate Change) has released a detailed guide on preparing Technology Action Plans (TAPs)¹⁹ (UNFCCC 2016). TAPs comprehensively cover action measures for prioritized technologies dissemination. Though these action plans are supported by national policies, they will cover a technology.

The World Bank has developed guidance series (World Bank 2010) on mainstreaming climate change adaptation at the programme level that is specific to agriculture sector. At a programme level, mainstreaming begins with stakeholder engagement by identifying key people and institutions and appealing to local communities. This is followed by assessment of climate risk. The preparation phase comprises strengthening institutional capacity and identifying and analysing adaptation responses. These constitute pre-implementation steps. Post implementation, the task is to monitor and evaluate, as well as share experiences to inform future mainstreaming tasks.

UNDP-UNEP have proposed a framework (UNDP-UNEP 2011) consisting of three components of mainstreaming adaptation :

The first component focuses on understanding climate change and development agenda links, or finding an entry point between the two. This entails understanding current efforts in mainstreaming adaptation and their outcomes and then subsequently determining the point from which activities can be pursued. For example, the possible entry points for national governments can be the environment plans, SDGs (Sustainable Development Goals) strategy or other long-term plans.

The second component involves mainstreaming, which focuses on integrating climate change adaptation into national policies, development plans and sector strategies, for example the entry points identified in the first component. Targeted information on impacts, vulnerabilities, risks and adaptation technology benefits helps insert the technologies into policy processes and related measures. This should be accompanied by communication strategies targeting the diverse stakeholder groups to convey the information. Best practices from technology pilots can serve as strong drivers for mainstreaming at different levels.

Finally, *the third component* aims to integrate climate change adaptation considerations into budgeting, implementation and monitoring to ensure that they become a part of standard operations. For example, adaptation indicators should be included in water policies or budget components of technologies for adaptation. Consultations with stakeholders are encouraged at every level and are seen as a crosscutting component in the framework.

The importance of mainstreaming climate change adaptation is widely agreed upon. Yet, its integration into the development frameworks of countries is not yet widespread. Three broad categories of barriers – those in governments, information gaps, and finance and capacity gaps – have hindered climate change adaptation mainstreaming (OECD 2006). In many governments there is inertia to change. There are direct trade-offs between economic priorities and measures to manage or confront climate change. Short-term economic benefits may be prioritized over long-term sustainability actions because of lack of political will (Huq, et al. 2003). In addition, public bodies often don't have effective guidelines and are inadequately equipped to facilitate mainstreaming. Information barriers can also hinder the planning process (Klein, et al. 2007) (Kok and de Coninck 2007). If there is insufficient information, resources from different plans may be used for activities that are lacking, or in the worst case, not advisable.

¹⁸ For definitions of Market and Non-Market Technologies, refer to the 'TNA Guide Note' at <http://www.techaction.org/Publications/TNA-Guidebooks>

¹⁹ http://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_

Finally, attracting financial resources for adaptation activities is relatively difficult (in comparison to mitigation activities such as those in industrial energy efficiency) because of a lack of a direct revenue stream in most in adaptation projects (OECD 2006). A water conservation technology may bring about water savings, but in most countries water resources are not priced high enough to recover their real value. Hence, there will be insufficient or no direct monetary savings. Lack of capacity, especially in least developed and developing countries, adds to the barriers.

Despite these barriers, there are opportunities to create enabling or conducive conditions for mainstreaming adaptation technologies. After the Paris Agreement of 2015, UNFCCC (2016) recognised that the processes to develop and implement National Adaptation Plans (NAPs) have the potential to address synergies between adaptation and development. UNFCCC also encourages countries to identify and define their adaptation needs as part of their overall development priorities. Intervention in mainstreaming climate change adaptation works at three levels (UNDP-UNEP 2011) :

- Strengthening the development base : These interventions include actions to enhance resilience and strengthen the country's overall development indicators for reduced vulnerability to climate induced adverse effects ;
- Promoting mainstream adaptation measures : These interventions focus on including climate change adaptation in policy frameworks ;
- Promoting specific adaptation measures : These are targeted interventions concerning specific problems, geographic zones and communities, thereby addressing issues not captured in the first two interventions.

Relevant measures for mainstreaming technologies for water sector adaptation are presented in the following section. These measures are also generally relevant for mainstreaming technologies for adaptation. They provide options for enhancing adaptation planning and mainstreaming in development planning processes, as well as opportunities for enhanced implementation.

1. Integrate climate change adaptation technologies with a development agenda

Technologies for adaptation in the water sector have significant overlaps with developmental issues. This makes it relevant to insert technology plans into larger development plans. It is important to ensure the decision-making process for development covers adaptation issues and technological solutions. If the country has an overall vision for development, it can inform the adaptation plans. For example, identifying priority sub-sectors, vulnerable zones and types of vulnerabilities is useful for pinpointing the gaps that

the water adaptation technologies can fill. Similarly, a formal process where sub-national bodies contribute to technology implementation can help make the dissemination process more efficient.

2. Disincentivize unsustainable technologies and incentivize technologies for adaptation

Technologies for adaptation are often not adopted because either there is no disincentive for switching from an unsustainable technology or the incentives from technologies for adaptation are not compelling enough to drive the change (Nygaard and Hansen 2015). For example, in most developing countries there is no 'fair' price on water resources for full recovery after a negative environmental impact. This implies, for example, that if a farmer has access to ground water he just has to dig a deeper tube well to counter the receding water table and continue with his practice of flood irrigation. The incentive to move toward sustainable micro-irrigation schemes is limited. In the longer run, the farmer may be forced to make a change when high salinity requires a switch to efficient measures. Consider the same situation in the context of access to ground water being regulated where the farmer has to pay for every unit. In this case, the incentive to make the change to efficient technologies is higher. This mechanism can work by incentivizing a technology, for example through subsidies on purchase of equipment, or through disincentives for conventional unsustainable technologies by, for example, levying environmental taxes.

3. Engagement with stakeholders

One way to facilitate mainstreaming of technologies for adaptation is to engage with different stakeholders at all levels, from inception through policy development, implementation and monitoring (UNDP-UNEP 2011). Private sector engagement can unlock potential financing sources. Similarly, engagement at the grassroots level can be useful in identifying and disseminating technological needs, making certain grassroots alternatives viable. The private sector can help improve value chains for technologies and design relevant awareness programmes. Mandates for engagement can often support technologies dissemination. For example, India is the first country in the world to have regulations for mandatory contribution to corporate social responsibility. The corporate sector now is participating in various development activities, many of which are oriented towards adoption of technologies for adaptation.

4. Research and development

Mainstreaming of technologies contributes to research and development by creating a facilitative research environment, an exchange of ideas and knowledge management. This will promote more user-friendly technologies, helping to translate needs into action. Engagement with research organizations can help build viable models out of prototypes, benefitting communities.

5. Coordination and alliances

Adverse impacts of climate change may be experienced locally, but to tackle the problem better coordination among various governmental and non-governmental agencies within a country is needed (OECD 2009). The department of environment and climate change cannot work as an independent entity and needs to ally with industry, agriculture, research and other sectors. Strengthening institutional mechanisms increases adaptation action efficiency. Information sharing alliances and regional networks can reduce duplication and strengthen capacities for implementation. Capacity building, development of locally adapted technologies and knowledge transfer can be pursued in developing countries through South-South cooperation.

6. Access to information

The main challenge in regards to information is that either too much unusable information is available, or it is inadequate for making credible policy decisions (OECD 2006). Researchers, development practitioners and policy makers have to contribute to the information that is used for context-specific decision-making. Many developing countries are taking steps toward building indicator systems for monitoring important sectors, which are then made available for development planning. However, many least developed countries have limited access to climate information and don't have the capacity to make decisions in regards to climate uncertainty. The role of information in evidence-based decision-making is crucial for mainstreaming adaptation measures. National governments have to work toward better collection, dissemination and access to information.

7. Developing climate risk screening tools

Climate risk screening tool development is closely related to access to quality information. Tools to identify risk are needed to recognize and categorize exposed areas and sectors. This enables efforts to be focused on exposed sectors, regions and activities (Huq, et al. 2003) (UNDP-UNEP 2011). Screening tools can also help identify key project variables affected by climate change, which in turn can facilitate

timely corrective and preventive measures. Though businesses may not directly understand adaptation, they often comprehend climate-induced risks and the need for their management. Climate risk screening tools can enhance private sector engagement in the mainstreaming process. Using them in a wide range of developmental projects and can greatly advance mainstreaming of climate risk responses in national policies.

Deployment and transfer of technologies for adaptation is contingent upon their local suitability and effectiveness in addressing vulnerability to climate change stressors. It is therefore important that technology prioritization takes these factors into account. If the technologies are implemented without recognition of relevant social contexts and environmental processes, they will be may make ineffective.

This chapter has introduced the prioritization process, along with its steps and common tools, for technologies and stakeholder engagement. Prioritization processes for technologies can help select and implement important adaptation measures for a country. Ensuring that they fit into the national vision and development priorities is the most pragmatic approach for mainstreaming at the policy level. In addition, there are opportunities to integrate climate change adaptation responses into development activities as a whole, and they should not be limited only to national boundaries. Countries can explore synergies with other counties through transboundary and regional cooperation.

CONCLUSION

This guide has introduced 102 adaptation technologies for strengthening the climate change readiness and resilience in the water sector. The adaptation technology list provided in this guide is not exhaustive as the technological landscape is dynamic and ever evolving, but it provides a solid foundation for adaptation planning processes and, consequently, technology prioritization and selection. This guide further seeks to support technology prioritization processes by presenting a number of tools and methodologies that can help to navigate the plethora of technologies available, and make the necessary selection in a structured and informed way.

The relevance of stakeholder engagement in technology selection and implementation processes should once more be underlined. There is a lot to be gained from engaging local stakeholders in water adaptation response – from better understanding of the issues and their causes on the ground, to ensuring technology implementation buy-in. For many water adaptation technologies, continued stakeholder engagement and commitment is the key to success and longevity. For example, ensuring efficiency of land use limitations for water quality requires that local stakeholders comply with land use limitations or regulations for reduced impact agriculture for better water quality. In a similar way, protecting coral and oyster reefs for coastal conservation is directly dependent on activities upstream, requiring broader stakeholder involvement and commitment in the source-to-sea continuum.

As technological advances for improved water management march forward, so does the science of climate change. Nevertheless, there are still large inherent uncertainties in climate change projections and understanding the climate change effects on water resources, especially at the local level. While climate models and downscaling approaches can help anticipate some changes to the water cycle, most of them are highly uncertain in understanding impacts at the basin and community levels. Furthermore, the climate change impacts on water resources may not be uniform – the same communities may face periods of both ‘too much water’ and ‘too little water’. Thus, planning for adaptation responses should never be approached in a simple one problem-one solution manner. Climate change challenges and their respective adaptation response options should be viewed as an interaction between a number of potential climate change impacts, variety of responses and their benefits.

Here, climate change adaptation plans, and integrated water resources management as an overarching approach to water resources management and development, play an important role. Implementing integrated approaches to water management helps to better understand and evaluate the interplay between the various challenges and their respective adaptation responses. It also supports creating a productive environment for stakeholder engagement processes, with a focus on equality and engagement. As a management approach, or rather a process, it considers not only the immediate proponents of a given intervention, but also stakeholders from related communities and sectors that have an impact on the quality of the resource, and the sharing of its benefits.

Finally, there are opportunities in implementing climate change adaptation technologies that deliver beyond the immediate water adaptation benefits. Many water adaptation technologies provide significant additional benefits, such as habitat protection, air quality, pollution reduction, and new income generation opportunities. This also creates better opportunities for financing interventions where investing in water adaptation technologies can not only meet various policy objectives, but also reduce potential human casualties and asset losses, and create new economic opportunities.

Thus by employing comprehensive assessments of the full extent of anticipated climate change impacts on water resources and society, and the prospective benefits of climate change adaptation technologies, there is a strong case for investment in climate change adaptation technology development and implementation in the water sector and beyond.

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ABOUT AUTHORIZING ORGANISATIONS

UN Environment – DHI Centre on Water and Environment

The UN Environment-DHI Centre for Water and Environment is a United Nations Environment Programme centre of expertise. The Centre was established in 2001 and is hosted by DHI Group headquarters in Denmark, an independent, international consulting and research-based not-for-profit foundation of more than 1000 employees and with more than 30 years of experience in water resources management. The Center is dedicated to improving the management of freshwater resources from the local to the global level.

UN Environment-DHI has become a core resource for UN Environment's work on freshwater issues and in delivering its Programmes of Work. The Centre's ability to draw on DHI's expertise in water and project implementation, as well as those of a broad network of partners, is one of its greatest strengths.

<http://www.unepdhi.org/>

The Climate Technology Centre and Network (CTCN)

The Climate Technology Centre and Network (CTCN) fosters technology transfer and deployment at the request of developing countries through three core services: technical assistance, capacity building and scaling up international collaboration. The Centre is the operational arm of the UNFCCC Technology Mechanism, it is hosted and managed by the United Nations Environment and the United Nations Industrial Development Organization (UNIDO), and supported by more than 340 network partners around the world.

<https://www.ctc-n.org/>

UNEP DTU Partnership

UNEP DTU Partnership (formerly UNEP Risø Centre (URC)) is a leading international research and advisory institution on energy, climate and sustainable development. As a UN Environment (UNEP) Collaborating Centre, UNEP DTU Partnership is an active participant in both the planning and implementation of UNEP's Climate Change Strategy and Energy Programme.

Through in-depth research, policy analysis, and capacity building activities, the Partnership assists developing countries in a transition towards more low carbon development paths, and supports integration of climate-resilience in national development.

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