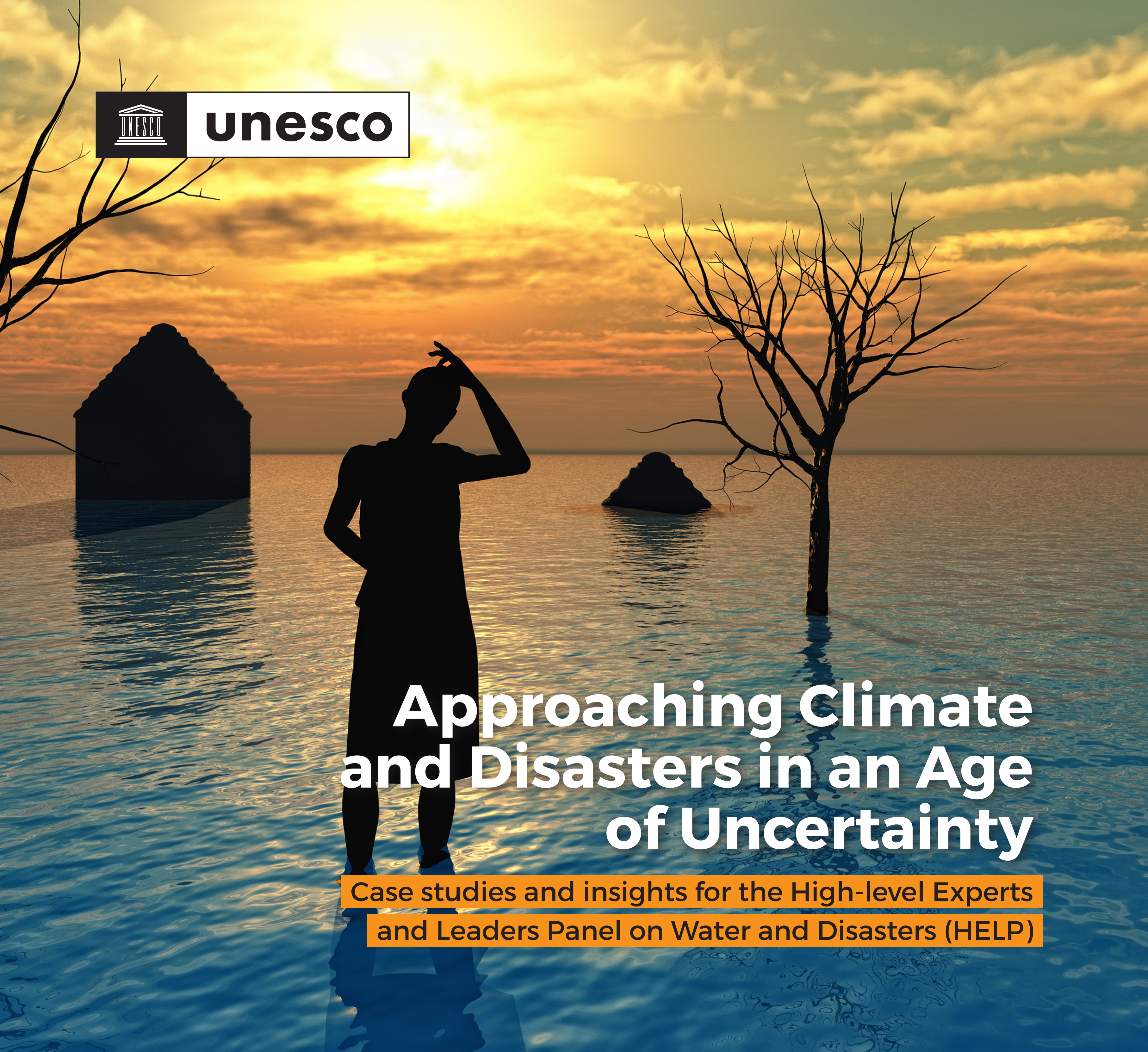

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Approaching Climate and Disasters in an Age of Uncertainty

Case studies and insights for the High-level Experts and Leaders Panel on Water and Disasters (HELP)

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SHORT SUMMARY

Bottom-up approaches for resilient water management in the face of hydroclimatic risks

Member States face the "no size fits all" challenge when implementing adaptation measures and defining actions to face climate change impacts and water-related disasters. In this context, bottom-up approaches present a good alternative for resilient water management in the face of climatic uncertainty. This publication follows the webinar series "Adaptation in an age of uncertainty: tools for climate-resilient water management approaches", co-organized by UNESCO-IHP, AGWA and ICIWaRM in 2020 and 2021, which reached more than 2 840 participants from 142 countries and aimed at introducing and promoting the benefits of bottom-up approaches, targeting local-level water management professionals and individuals working in climate and water policy and planning.

This publication aims to bridge the gap between climate and disasters, in the face of the uncertainties that climate change poses to water managers and policymakers. Composed of a compilation of worldwide case studies, it provides examples of innovative water management and climate risk assessment approaches. The publication also highlights the National Determined Contributions (NDCs) and National Adaptation Plans (NAPs) with the aim of identifying links between these high-level frameworks, DRR and water issues, and describing how the policy-practice linkages can be turned into action.

More than 2 840 participants from 142 countries

benefited from the webinar series on new climate-resilient water management approaches

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"Since wars begin in the minds of men and women it is in the minds of men and women that the defences of peace must be constructed"

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List of Abbreviations/Acronyms

ABCD Centre	Global Water and Climate Adaptation Centre: Aachen – Bangkok – Chennai – Dresden
AGWA	Alliance for Global Water Adaptation
AHP	Analytical Hierarchy Process
BPDP	Bangladesh Power Development Board
CAF	Corporacion Andina de Fomento Development Bank of Latin America
CCA	Climate Change Adaptation
CDKN	Climate and Development Knowledge Network
CRA	Climate Risk Assessment
CRM	Climate Risk Management
CRIDA	Climate Risk Informed Decision Analysis
DAAD	German Academic Exchange Service
DGIS	Directorate-General for International Cooperation, Netherlands
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DTF	Decision Tree Framework
EEDS	Eco-Engineering Decision Scaling
EWERI	East Water and Environmental Research Institute
FC	Febres Cordero
GCAP	Global Climate Adaptation Partnership (UK) Limited
GCF	Green Climate Fund
GCM	Global Circulation Model
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HELP	High-level Experts and Leaders Panel on Water and Disasters
ICIWaRM	International Center for Integrated Water Resources Management
IHP	Intergovernmental Hydrological Programme of UNESCO
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resource Management
LAC	Latin America and the Caribbean
M&E	Monitoring & Evaluation
MWA	Metropolitan Waterworks Authority
NAPs	National Adaptation Plans
NBS	Nature-Based Solutions
NDCs	Nationally Determined Contributions
NDRI	Nepal Development Research Institute
NWSDB	National Water Supply and Drainage Board
RCM	Regional Climate Model
RDM	Robust Decision Making
PAC	Practical Action Consulting, Nepal
RIMES	Regional Integrated Multi-Hazard Early Warning Systems
SA	Sustainability Assessment
SDGs	Sustainable Development Goals
SFM	Sendai Framework Monitor
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNFCCC	UN Framework Convention on Climate Change
USACE	U.S. Army Corps of Engineers
USAID	United States Agency for International Development
WASH	Water, Sanitation, and Hygiene
WEAP	Water Evaluation And Planning
WTP	Water Treatment Plant

Foreword

Over the past years, climate science became increasingly clear on the links between climate change impacts and natural disasters, particularly water-related disasters. As per the 6th IPCC Assessment Report (August 2021), “climate change is intensifying the water cycle”, bringing unprecedented flooding, and increased magnitude of droughts, among other water-related hazards, which will be more frequent and intense affecting already vulnerable areas worldwide.

Climate risk assessment is nowadays in the spotlight due to the frenetic climate variabilities and changes many areas in the world have been facing. For decades, forecasting science has focused on predicting the time and place of hazardous events, but climate variability and its associated uncertainty have posed a challenge to the reliability of such predictions. There is increasing pressure for decision-makers to make timely and robust choices to protect communities and ecosystems. Transposing actions from high-level frameworks, such as the Paris Agreement or the Sendai Framework for Disaster Risk Reduction, into local action is challenging, particularly in developing countries where the allocation of scarce resources needs careful consideration.

Member States face the “no size fits all” challenge when implementing adaptation measures and defining actions to face climate change impacts and water-related disasters. In this context, bottom-up approaches present a good alternative for resilient water management in the face of climatic uncertainty. Such approaches differ from the dominant paradigm guiding water management for the past half-century, namely the assumption that the past can be used to predict and plan for future challenges. Moreover, working from the bottom-up allows for defining robust adaptation measures, tailored to the communities needs and adjusted to their human and economic resources. The Climate Risk Informed Decision Analysis (CRIDA) tool, featured in this publication, is a bottom-up approach developed by UNESCO-IHP and its partners which has been increasingly implemented by decision-makers, notably in Latin America and Africa.

UNESCO’s Intergovernmental Hydrological Programme (IHP) recognizes the great challenges Member States face concerning water management. Since the 1970’s UNESCO-IHP has supported the advance in the scientific knowledge of water issues while also providing a platform for the Member States to enhance capacities and support policy development. Entering its ninth phase, devoted to promoting ‘Science for a Water Secure World in a Changing Environment’ (IHP-IX 2022-2029), UNESCO-IHP places water-related extremes as part of the main global water challenges. Improve scientific knowledge, methodologies and tools in addressing water-related disasters for timely forecasting are among the objectives of IHP for this new period. These actions are aligned with UNESCO’s Draft Programme and Budget for 2022-2025 (41 C/5), particularly those defined under Major Programme II: Focus in 2021-2025, Outcome 3: “Enhance knowledge for climate action, biodiversity, water and ocean management and disaster risk reduction”.

This publication follows the successful series of seven webinars entitled “Adaptation in an age of uncertainty: tools for climate-resilient water management approaches”, co-organized by UNESCO-IHP, Alliance for Global Water Adaptation (AGWA) and the International Center for Integrated Water Resources Management (ICIWaRM) in 2020 and 2021, which reached more than 2840 participants from 142 countries and aimed at introducing and promoting the benefits of bottom-up approaches, targeting local-level water management professionals and individuals working in climate and water policy and planning.

“Approaching Climate and Disasters in an Age of Uncertainty” aims to be a source to reimagine and readdress water management and climate risk assessment through locally defined policies and create a binding between these two subjects. Through the various case studies compiled, examples can be found of new ways to address the problematic of hydro-climatic challenges and the proof that a change of paradigm is possible by providing a series of good practices developed worldwide. This publication is also an invitation to question the current paradigm in water management and climate risk assessment and to consider new methodologies to be applied to the incessant duty of achieving water security and climate-proof strategies. The publication has also looked into National Determined Contributions (NDCs) and National Adaptation Plans (NAPs) with the aim of identifying links between these high-level frameworks, DRR and water issues, and describing how the policy-practice linkages have been turned into action.

UNESCO-IHP thanks all contributors to this special publication, notably AGWA for taking the lead in its development and the authors that have collaborated with their experiences and expertise. A word of appreciation goes to the Flanders Fund-in-Trust for the support of UNESCO’s activities in the field of science (FUST) and especially for supporting this publication and other resilience-building activities through the project “Climate-resilient water management approaches: Application towards Climate Action and 2030 Development Agenda” (2020-2021).

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Introduction

To most victims of an extreme tropical cyclone such as a super-typhoon, a multi-century drought, or a millennial flood event, the links between climate change and the water cycle may seem academic and dry, irrelevant to their personal grief and loss.

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However, climate science literature is quite extensive about these connections, and the implications deserve clear translation into the language of disaster preparation, management, and response programs globally. How do we get ready for extreme events beyond our experience, whose timing and magnitude are difficult to predict over public policy timescales? If science tells us there are limits to our knowledge, how do we design measures to reach tangible disaster response and recovery systems to protect our communities, ecosystems, and economies? Do we face new risks by failing to imagine what may yet emerge this century?

Climate change increases variability in the water cycle, inducing extreme weather events, reducing the predictability of water availability, affecting water quality, all while threatening sustainable development, biodiversity, cultural and recreational uses, and the overall enjoyment of the human rights to water and sanitation worldwide. We are likely even seeing the emergence of new types of extreme events.

While water is at the heart of many of the manifestations of climate change, so too can it be central to efforts to adapt — representing an entry point for sustainable development, disaster risk reduction and preparedness, and climate resilience. Water is the hazard, but water resilience is the solution.

The international community has come together to create pathways towards addressing these challenges, resulting in policy agreements and frameworks such as the United Nations Sustainable Development Goals (SDGs), the Sendai Framework for Disaster Risk Reduction, and the Paris Agreement.

Not coincidentally, all three of these central frameworks and agendas were either created or came into force around the same time period in 2015. Now, seven years later, the persistent issue is how to turn commitments — sometimes abstract, sometimes quite specific — into tangible actions and meaningful results at the national level all the way down to the community scale.

As countries begin the process of identifying, resourcing, and implementing projects for sustainable development, disaster risk reduction (DRR), or climate resilience, tools and methodologies for project planning, design, and operational decision making take on even more significance.

UNESCO is undertaking this flagship publication as part of its longstanding involvement in water management and science over the past 70 years. For the last five years in particular, UNESCO has been active in developing and promoting the use of what are known as bottom-up approaches to address climate risks and other uncertainties in water management — an effort simultaneously undertaken by a growing set of partners ranging from state and national governments to resource management agencies and multilateral development banks.

Working with Uncertainty in Water Decision Making

These bottom-up approaches differ from the dominant paradigm guiding water management for the past half-century — namely the assumption that we can use the past to confidently predict (and plan for) the future. Contrastingly, top-down approaches rely upon the accuracy of climate predictions from global circulation models (GCMs) as the basis for decision making. The tools and models used in large-scale forecasting can bring in their own elements of uncertainty, presenting decision makers with a wide range of possible futures that could be used in their analysis. The scale of analysis presents challenges too, as forecasting tools are generally designed to present data at larger geographic scales, with coarser resolutions and therefore greater uncertainty at the regional and local scales at which many adaptation and water management decisions are made. Further still, there is great subjectivity in choosing which set of future hydroclimatic conditions to plan, design, or invest in (Mendoza et al., 2018).

As climate change and other drivers lead to increasing variability and uncertainty for planners and decision makers, bottom-up approaches have been developed to confront these uncertainties by focusing on stakeholder-defined measures of success as a starting point. Emphasis is placed upon gaining a more complete understanding of a location's vulnerabilities and learning under what conditions the water resources "system" no longer functions. Examples of bottom-up approaches include Climate Risk Informed Decision Analysis (CRIDA), published by UNESCO and the International Center for Integrated Water Resources Management (ICIWaRM), the World Bank's Decision Tree Framework, Decision Scaling, and Adaptation Pathways (an approach emerging from the Netherlands), among others.

Supporting the HELP: Taking Action to Address Water and Disasters

The purpose of this publication is to provide evidence and recommendations to the High-level Experts and Leaders Panel on Water and Disasters (HELP) on the use of a specific set of climate-resilient water management tools and approaches as means of improving national climate and disaster risk management (DRM) strategies and addressing the impacts of water-related hazards on vulnerable communities.

This publication will provide a better overall understanding of where bottom-up approaches fit into the wider policy context in two steps. First, the guidance will examine the broader relationship between national disaster policies and climate adaptation frameworks. Second, a compilation of global case studies will showcase the applicability of these approaches in a range of water management contexts, demonstrating the ways in which technical tools can support decision makers and policy makers in achieving their policy commitments.

Case studies were featured in a long-standing webinar series entitled *Climate-Resilient Water Management Approaches: Adaptation in an Age of Uncertainty*, led by UNESCO, the Alliance for Global Water Adaptation (AGWA), and the International Center for Integrated Water Resources Management (ICIWaRM) which took place in 2020-2021. This report will build upon the efforts of the webinar series, bridging elements of national policy making with on-the-ground examples of practical solutions to climate- and disaster-related challenges.

Disaster and Climate Policies: Alignment Through Water

Introduction to Global Disaster and Climate Policy Frameworks

Over the previous two decades, the number of reported natural and biological disasters has skyrocketed. The 2022 Global Assessment Report on Disaster Risk Reduction reported that the number of disasters reported annually between 2001 and 2020 rose to between 350-500, compared to an average of 100 annually between 1970 and 2000. These included geophysical hazards such as earthquakes, tsunamis, volcanoes, climate- and weather-related events, and biological hazards, including agricultural pests and epidemics. If current trends continue, the occurrence of disasters worldwide could rise by 40% between 2015 and 2030 from 400 to 560 annually (UNDRR, 2022).

In 2015, UN Member States adopted the Sendai Framework for Disaster Risk Reduction 2015-2030 to reduce and prevent disasters, loss of lives, livelihoods, economic losses, and infrastructure damage. Other significant international frameworks such as the UN Framework Convention on Climate Change (UNFCCC) Paris Agreement, and the 2030 Agenda for Sustainable Development (SDG 2030) also address DRR as an integral part of sustainable development, highlighting the complex relationships between climate change, human development, and DRR.

Building resilience to shocks and stressors lies at the heart of the Paris Agreement, Sendai Framework, and SDGs. Yet, in practice these frameworks' processes and activities are operationalized independently and lack policy coherence (UNDRR, 2021a). New efforts to implement institutional reforms and coordinate planning through so-called National Platforms for DRR do exist and are being expanded in many countries. While the characteristics of each Platform vary from country to country, they broadly support cross-sector and cross-stakeholder coordination between DRR, sustainable development, and climate change adaptation (CCA) through the appointment of National Sendai Focal Points (Mysiak, 2021). However, these front-line agencies often continue to face institutional, technical, and financial capacity constraints when integrating DRR and national CCA policies and plans (UNDRR, 2019).

One of the challenges facing policy makers working on effective coordination is the issue of balancing short-term benefits with long-term planning. Both DRR and CCA aim to minimize risk over the long term and increase resilience. Furthermore, the requirement for medium- to long-term planning for climate action, notably in managing risk across timescales, overlaps with the need for short-term risk reduction. However, DRR often emphasizes underlying, short-term risks, while CCA focuses on inherent vulnerabilities (RCRCCC, 2022).

Nevertheless, there are successful examples of integrating DRR with CCA to reduce vulnerability by designing, implementing, and evaluating multi-hazard risk reduction strategies, policies, and measures (explored later in this report's case study collection). Both priorities require a comprehensive understanding of the vulnerability, risk factors, and societal attitudes while emphasizing systemic risk mapping, planning, and monitoring.

Connecting National Response Options for Disasters and Climate

Through measures that include mainstreaming resilience into national policies and seeking solutions to reduce community vulnerability and exposure to climate impacts, more countries are committing to address climate change and reduce risks. At the national level, most DRR requests focus on adaptation measures, including creating risk and vulnerability maps and improving capacity for health and disaster management, rather than cross-cutting resilience initiatives. Within any given country, multiple agencies may be responsible for developing and implementing CCA processes through Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs) or through the development of national and local DRR plans under the Sendai Framework.

Therefore, NDCs and NAPs are one important way for communicating countries' adaptation and mitigation plans and demonstrating DRR planning linkages. Drafting an NDC provides an opportunity to bridge gaps and encourages actors to recognize that reducing and preparing for disaster risk today is crucial to short-, medium-, and long-term CCA planning and finance (RCRCCC, 2022).

Critically, countries are utilizing their NDCs to reduce the risks and impacts of disasters even as the frequency of their occurrence continues to rise. Recent analysis indicates that 83 of the 190 countries that submitted their first NDC included DRR and/or DRM in some capacity (NDC Partnership, 2021; UNFCCC, 2020b). For example, Bangladesh, one of the Southeast Asian countries most affected by massive flooding in 2017, discusses flood and cyclone shelters in its NDC (NDC Partnership, 2019).

However, according to the analysis of national reporting to the NDC Partnership, one of the DRR-related activities with lower rates of support is integrating NDCs into broader national planning, budgeting, and revenue streams (RCRCCC, 2022). Other issues identified were promoting gender equality, exchanging knowledge and best practices, and informing and drawing attention to the general public. On a positive note, there is already synergistic evidence of cross-cutting planning in the Member States' reporting on NDCs under the Paris Agreement. Since implementing the Sendai Framework, more than 50 nations have integrated DRR or DRM into their NDCs. As an example, the Sendai Framework was explicitly mentioned in the NDCs of both Colombia and India (UNDRR, 2019).

Similarly, the Sendai Framework was not included explicitly in initial NAP guidelines, which primarily concentrate only on hazards related to the climate. However, the development of NAPs through comprehensive national and local adaptation planning has recently increased, when countries were given additional technical NAP guidelines intended to promote DRR synergy in national adaptation planning (UNDRR, 2020a). This technical guidance offers practical recommendations on when and how to incorporate DRR into adaptation planning for national governments, institutions in charge of adaptation planning, and various adaptation actors, giving countries a better ability to consider multiple risks when making development decisions on climate and disaster resilience building.

Water is a binding threat that affects several sectors when it comes to DRR. Countries already endure climate impacts through water across sectors, and climate change is anticipated to increase global water demand, heightening competition for water resources as the timing, quantity, and quality of available water become less predictable and variable (Timboe et al., 2020). Water resources are explicitly mentioned in 90% of the intended NDCs from 2015, including an adaptation component. Notably, 80 NDCs indicate that water drives climate adaptation activity, and 89% of them prioritize investment in water infrastructure, institutions, or governance (GWP, 2018). No intended NDCs, however, mention the needs for resilient water management and policy alternatives. This oversight is worrisome since NDC agreements with implicit water components could include (or lead to) conflicting commitments over water. Given a limited water supply, for example, many sectors (e.g., cities, energy, and agriculture) may not have enough water to meet NDC goals (Timboe et al., 2020).

NAPs should emerge from country-level adaptation and resilience-building processes (GWP, 2019); therefore, understanding national development priorities, pressures, and drivers allows appropriate objectives to integrate water into a NAP's vision and mandate. Including water in the NAP process increases water security and climate resilience, which promotes objectives such as improving water management approaches. This integration could complement the delivery of adaptation commitments in a country's NDC, including implementation action prioritized in the country's National Communication, delivery on the Sendai Framework, and the achievement of a country's SDG targets related to water and climate resilience, along with other SDG goals.

Devising, Measuring, and Reporting Across Frameworks

Because of policy instruments and frameworks including NDCs, Adaptation Communications, NAPs, and the Sendai Framework's Target E — which aims to significantly increase the number of countries with national and local disaster risk reduction plans — countries are articulating their national (climate) priorities in order to implement them by 2030 in an integrated manner to ensure coherence between DRR, climate change, and sustainable development policies and practices (UNDRR, 2017). Monitoring and Evaluation (M&E) serves an important role in tracking progress against national commitments.

Across the range of programming for CCA, DRR, and sustainable development, countries are working to put the necessary arrangements in place to gather data and information on new and ongoing interventions. The goal is to evaluate their efficacy and determine whether or not to make real-time adjustments based on meeting (or missing) targets. NAPs, for example, often incorporate elements of M&E directly within the plans themselves.

Similarly, during implementation for achieving its global targets, the Sendai Framework established a set of metrics to assess global progress and identify trends in reducing risks and losses. Metrics outlined in the Sendai Framework are then used in conjunction with country-specific standards to evaluate targets.

Europe is the only continent where countries consistently make M&E a regular aspect of their NAP policy cycles (EEA, 2020); however, a growing number of developing countries are tracking and reporting their NAP progress. As of November 2020, 57 countries with M&E as part of their proposals had their NAPs approved, including Colombia and Ethiopia (Leiter, 2021). Part of this trend was due to Green Climate Fund NAP readiness funds. Another element behind this trend was donors reacting to Paris Agreement Article 13, Paragraphs 14 and 15, promoting support for developing countries in adaptation planning and transparency. Anchoring M&E requirements in national climate laws also encourages successful implementation (Leiter, 2021).

Progress is being made around incorporating M&E within DRR programming. Since 2015, most countries have revised or created new national DRR strategies following the adoption of global frameworks, goals, and targets. While key elements around M&E are sometimes developed after the adoption of national policies in some countries, the majority already have a monitoring framework in place from the inception of the DRR strategy development. The sequencing of the documentation may vary on a country by country basis, with some DRR strategies functioning as "living" documents and evolving as a result of regular updates.

Within the M&E process — regardless of a project's thematic purpose — it is important to define which areas will be evaluated using qualitative and quantitative performance metrics as part of progress, effectiveness, and gap analysis. This holds true for integrating water in the NAP process and delivering water-related adaptation (GWP, 2019). More generally, M&E frameworks will ideally feature an inclusive process encompassing the range of stakeholders involved in building a project's shared vision. Specific metrics for documenting progress, measuring and communicating effectiveness, and reviewing gaps should be defined.

Challenges still remain in prioritizing and operationalizing M&E across CCA, DRR, and sustainable development programming. It is worth noting that several countries have experienced issues that have hindered the development of DRR strategies at the national and local levels. For example, countries' efforts to establish, formalize, and approve their national DRR strategies following the Sendai Framework, the SDGs, and the Paris Agreement were greatly hampered by the recent COVID-19 pandemic (UNDRR, 2020a). Similarly, on the climate side, recent analysis has shown that although establishing or applying NAP M&E systems has increased by 40% in 2020 compared to 2017, the majority are not yet operational (Leiter, 2021). Further, not enough is currently known about NAPs' implementation progress, and even less about their effectiveness due to methodological challenges around M&E. That includes a lack of shared metrics to quantify adaptation action success, unavailability of data, uncertainty regarding intervention consequences, intervening socio-economic variables, and the extended duration over which climate impacts unfold (NDC Partnership, 2020).

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Who is Involved in National DRR and Climate Policies?

Both at the donor level and within national government agencies, humanitarian and development departments are not typically connected. Consequently, steps to reduce disaster risk in the short-, medium-, and long-term are not often reflected in NDCs or NAPs, which are typically the province of national development, environment, or planning agencies (RCRCCC, 2022). There is frequently a divide at the donor level between development departments — which are traditionally tasked with long-term poverty reduction and the promotion of sustainable development — and humanitarian departments — which frequently deal with immediate relief needs resulting from disasters.

Commonly, at the national government level, the Ministry of Interior, Ministry of Defense, or occasionally the Ministry of Development or Ministry of Economic Affairs are mandated to lead DRR planning and policy development. In contrast, the Ministry of Environment or a recently established Climate Change Office typically lead CCA efforts at the national level (though the context varies in each country). Considerations around water are generally siloed under the remit of a Ministry of Water or similar agency, leading to DRR and CCA policies that are not always aligned with other national frameworks, such as national water management plans, water supply and sanitation strategies, and transboundary water frameworks or agreements.

The climate crisis necessitates breaking silos across all phases, from planning to implementation to monitoring and reporting. Since DRR and CCA are issues that affect many industries and socio-economic sectors, taking isolated action is rarely effective; hence, formulating, evaluating, and implementing strategies must be done cross-sectoral (UNDRR, 2019). In addition, uncoordinated sectoral responses might also be unproductive or, in some cases, even counterproductive since they can raise another sector's vulnerability or lower its adaptation effectiveness (UNDRR, 2018). This is especially true for issues around water, given its importance to all sectors.

Creating Policy "Win-Wins": Water as the Great Connector

Water is mentioned in many national climate commitments, disaster preparedness documents, and sustainable development plans, typically as a source of climate risk (e.g., floods, droughts) or as a "sector" requiring specific interventions, especially for new storage and other types of infrastructure investment. Unfortunately, water is very rarely described as a resource that can simultaneously support climate-resilient development and risk reduction.

Further deepening the risk of mistreating water, very few national policies and commitments acknowledge that CCA itself may alter water use and management patterns. Effective climate action can represent an intensification of water use in some cases, which also means that the risks of conflict between sectors, projects, and even across political and institutional boundaries is heightened. For example, shifts in irrigation needs may end up conflicting with both water-intensive clean energy investments and expanding water supply and hygiene needs for rural communities and the urban poor.

As a result, climate-related water consumption and management changes should also be an issue that countries can anticipate and prepare for, implementing policies that reduce the likelihood of conflict over water resources as countries work towards DRM, adaptation, and sustainable development.

By increasing collaboration and coordination at the national level between ministries and sectors, investments in water resilience can help ensure that both mitigation and adaptation actions are coherent and effective. Water resilience is an emerging practice, but one that builds on concepts such as Integrated Water Resources Management (IWRM) and the water-energy-food (WEF) nexus that recognize the cross-sectoral nature of water and its central importance to adaptation and resilience (GCF, 2019).

In recent years, the scientific community has also come to recognize the centrality of water in addressing climate change. Echoing this sentiment, the IPCC's Sixth Assessment Report Working Group 2 identified that "water-based adaptation" should be the centerpiece of efforts to anticipate and respond to climate impacts. Countries have started to heed the call, and the vast majority of the 2020-2021 NDCs and NAPs include water as a critical sector. For example, Costa Rica's NAP identifies water's fundamental role in the country's development and aims to strengthen conditions for the sustainability of water resources in the face of climate change in order to ensure the success of other sectors such as agriculture, livestock, and energy (Dirección de Cambio Climático, 2022). Still, more work remains to build comprehensive water resilience into these plans and policies.

Policy-Practice Linkages Turning Commitments into Action

Using the frameworks and policy instruments outlined in the preceding sections, countries have ample opportunities to make known their goals and commitments around DRM, CCA, and sustainable development, including resilient water management. Moving from words to actions, however, remains a complex and challenging feat. Operationalizing the concept of water resilience requires engagement across levels of governance and utilization of appropriate tools to help diagnose challenges and assess potential DRM, adaptation, and sustainable development solutions.

Often, the solutions to these challenges take the form of infrastructure, whether traditional, nature-based, or a "green-gray" hybrid approach. In this sense engineers, resource managers, and utilities serve as conduits for development actions. As developing countries plan and build new infrastructure, they are presented with an opportunity to design with the foresight to meet climate adaptation and DRM objectives, while simultaneously advancing economic development, responding to natural hazards, and addressing rapid urbanization (Stakhiv & Hiroki, 2021). In other cases, infrastructure presents the solution to a specific geo-climatic or hydrologic challenge, requiring an understanding of how to plan and design in the face of uncertainty. In either scenario, countries are conscientious of the fact that high-level commitments to global frameworks must eventually lead to practical responses and interventions.

Scale and scope are important considerations. National commitments are most often achieved not through broad, sweeping country-wide mandates and laws, but instead through the culmination of a myriad of smaller, subnational and regional actions involving diverse stakeholder groups. In tandem with (or shortly after) finalizing national climate and development plans, countries work to establish programs and project pipelines to facilitate implementation of interventions aligned with their commitments. This involves identifying pathways to facilitate financing, as well as deeper engagement at the local and regional levels. Ideally, these programs include linkages between multiple sectoral targets and across policy frameworks.

Many policy makers are coming to understand that distinct approaches to adaptation, DRM, and resilience building may vary in their usefulness, efficacy, and return on investment. Existing attempts to align sectors and projects, such as Integrated Water Resource Management (IWRM) or water-energy-food nexus approaches, tend to minimize uncertainties in future climate impacts, assuming that sharing of water resources can be optimized. Identifying and choosing projects that will yield the best outcomes across categories remains a daunting task in an era of uncertainty. An emerging set of approaches to assess and address risk offer opportunities for decision makers to quantifiably identify tradeoffs between interventions and select the best options based on their particular goals and contexts.

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> Many policy makers are coming to understand that distinct approaches to adaptation, DRM, and resilience building may vary in their usefulness, efficacy, and return on investment.

Emerging Best Practices for Addressing Climate Uncertainty in Water Management

Each year the sense of urgency grows around the need to take more action on climate change. New research and proclamations, such as those in the Working Group 2 contribution to the IPCC Sixth Assessment Report (2022), highlight the changes already manifesting in global hydrological cycles. In spite of ample attention on the topic — and a clear mandate for action — it is still incredibly difficult to predict future water challenges in an increasingly complex and uncertain world. Decision makers and resource managers must factor in numerous and cascading uncertainties, including "emerging socio-economic circumstances, demographic and urbanization trends, and eco-hydrological conditions" (Mendoza et al., 2018). Such uncertainties affect how to plan and make decisions for risk reduction and ensuring a water-resilient future. While the impacts of climate change are intrinsically dangerous, part of our crisis is also a failure in our current decision making systems.

Decision makers remain confronted with basic questions: Should we invest to minimize risk? How much should we invest? How can we justify a particular decision, given all the uncertainties? How do we plan for an action that is neither too early nor too late? Perhaps most importantly, how do we convey the resulting analyses, built on a pyramid of uncertainties, to the public and to political decision makers?

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Over the past two-plus decades, decision makers and resource managers have relied upon GCMs as the best source of information. These tools, however, are often too coarse in terms of spatial and temporal resolution to accurately or confidently inform decisions at the "problemshed" scale — often the catchment or community level (Garcia et al., 2014) — where DRR and climate adaptation actions generally occur. Projections tend to focus on the mean and lack the ability to inform on climate extremes (Olsen and Gilroy, 2012; Verbist et al., 2020), making them even less effective as tools to prepare for climate-related disasters.

As an alternative to more top-down approaches that rely upon the accuracy of climate predictions from GCMs as the basis for decision making, a new suite of decision making approaches have emerged over the past ten-plus years. These bottom-up approaches differ from the dominant paradigm guiding water management for the past half-century — namely the assumption that we can use the past to confidently predict (and plan for) the future. As climate change and other drivers lead to increasing variability and uncertainty for planners and decision makers, bottom-up approaches have been developed to confront these uncertainties by focusing on stakeholder-defined measures of success as a starting point, rather than scenario-driven projections.

Identifying the specific water-related challenge is the first step of bottom-up approaches. Emphasis is placed upon gaining a more complete understanding of a location's vulnerabilities and learning under what climatic or other socio-ecological conditions a hydrological system no longer functions adequately (i.e., meeting stakeholder-defined performance needs). To explore the tradeoffs of potential interventions (e.g., hard infrastructure, nature-based solutions (NBS), operational or management changes, etc.), climate stress tests are used to assess performance across a range of plausible climate and non-climate changes.

The concept of "bottom-up approaches" represents a suite of complementary frameworks developed by several institutions in recent years, each sharing a core set of principles around stakeholder involvement and localized definitions of system success and failure. Examples include:

- Climate Risk Informed Decision Analysis (CRIDA) (Mendoza et al., 2018)
- World Bank Decision Tree Framework (DTF) (Ray and Brown, 2015)
- Decision Scaling (Brown et al., 2012)
- Eco-Engineering Decision Scaling (EEDS) (Poff et al., 2016)
- Adaptation Pathways (Haasnoot et al., 2013)
- Several others, both formal and informal

Decision makers can choose among the different approaches based on their needs: Are they reoperationalizing existing infrastructure? Focusing on economic justification? Planning with nature-based solutions in mind? Operating in data scarce environments? In addition to requiring different inputs and levels of involvement by implementers, bottom-up approaches can vary in their area of emphasis. Some bottom-up approaches place more of an emphasis on the robustness of solutions to extreme events. Others emphasize maintaining flexibility to dynamic conditions and multiple possible futures, while still others take an integrated approach and focus on tradeoffs between options (Mauroner et al., 2021).

Bottom-up approaches align with traditional engineering planning processes, offering a complement to approaches such as IWRM while incorporating elements of decision making under uncertainty. With stakeholder engagement and context specificity being central to bottom-up approaches, there is also strong alignment with emerging paradigms in the adaptation community such as the Principles for Locally Led Adaptation (GCA, 2021).

> “
> Identifying the specific water-related challenge is the first step of bottom-up approaches. Emphasis is placed upon gaining a more complete understanding of a location's vulnerabilities and learning under what climatic or other socio-ecological conditions a hydrological system no longer functions adequately.

Case Studies

Bottom-up Approaches for Disaster Risk Management and Climate Change Adaptation in Action

The following sections present illustrations of technical, on-the-ground programs being implemented to help address disaster risk or climate impacts. They have each been featured in an earlier webinar series spanning 2020-2021 on Climate-Resilient Water Management Approaches: Adaptation in an Age of Uncertainty. In each case, acute or slow-onset threats are impacting water resources and human livelihoods.

The global set of case studies is meant to represent ways in which national policies manifest in local or subnational programs and projects, whether through securing continued delivery of urban water supplies in the face of drought, identifying hazards in the water-energy nexus, developing basin-wide sustainability strategies, or a number of other contexts. Case studies share a common set of bottom-up principles in the way they assess localized risk and determine acceptable levels of performance through stakeholder engagement. Bottom-up approaches are used to identify climate risks and other uncertainties, and analyze potential interventions to build resilience in support of DRR, CCA, and sustainable development.

Case studies within this report are shared as part of UNESCO's continued efforts to disseminate scientific knowledge and new innovations while driving the integration of sound science in water governance instruments, as laid out in the ninth phase (2022-2029) of the Intergovernmental Hydrological Programme (IHP): "Science for a Water Secure World in a Changing Environment" (IHP-IX).

Towards Climate-Resilient Urban Water Supply in Bangkok, Thailand

Prepared by Rachel Koh[1] and Mukand S. Babel[2]

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[2]Asian Institute of Technology

The municipal water supply system of Bangkok, the capital city of Thailand, is of particular interest given the service areas and the location of the raw water intake points. Extracting water from the Chao Phraya River Basin — the largest and most important basin in Thailand — the Metropolitan Waterworks Authority (MWA), the water utility of Bangkok, must ensure that water demand quantities are met with acceptable quality.

With municipal water supply having the highest water allocation priority (Takeda et al., 2016), water quality proves to be the greatest challenge for the utility. As illustrated in **Figure 1**, the water quality at the intake point is determined by several variables (block arrows), which could subject the system to problems such as saltwater intrusion. Examples include demand, river flow from upstream, and water level from downstream. Each variable is accompanied by a non-exhaustive cloud of uncertainty aggravated by climate change, and the assumptions involved in the projection of each variable (in top-down approaches) could compound or magnify the overall uncertainty when evaluating the system for future adaptation responses.

Given the complexity of the system and the inherent uncertainties involved, a modified planning process is introduced to develop an understanding of climate change-related critical thresholds. Adhering to the principles of the CRIDA framework, these critical thresholds are estimated from the perspective of system stakeholders and should form the basis for climate change adaptation interventions that the utility could undertake. The contribution of this example is two-fold: 1) a modified CRIDA framework to identify climate risks for localized planning and adaptive solutions, and 2) a practical case study to demonstrate the use of the approach in managing a municipal water supply system in Bangkok, Thailand.

Primary steps of the modified framework (**Figure 2**) include: (a) identifying critical thresholds that impact the system's performance, (b) unearthing the system vulnerabilities through a stress test (scenario analysis), and (c) identifying feasible adaptation interventions.

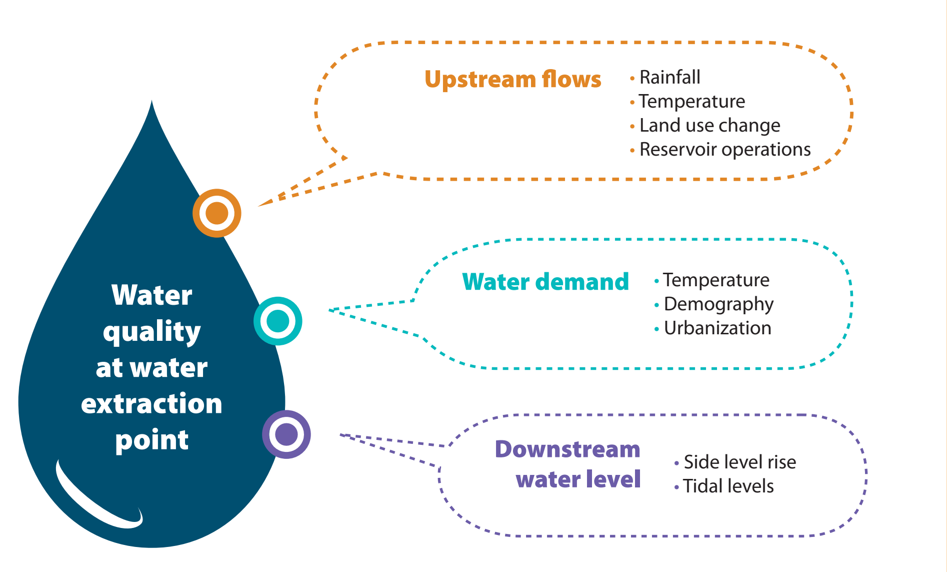

Figure 1

Adapted illustration of uncertainty present in a municipal water supply system of Bangkok. The variables in the block arrows directly affect the performance of the system, while the clouds represent other sources of uncertainty in the system. © Koh et al., 2022. Published by Elsevier B.V. CC BY 4.0

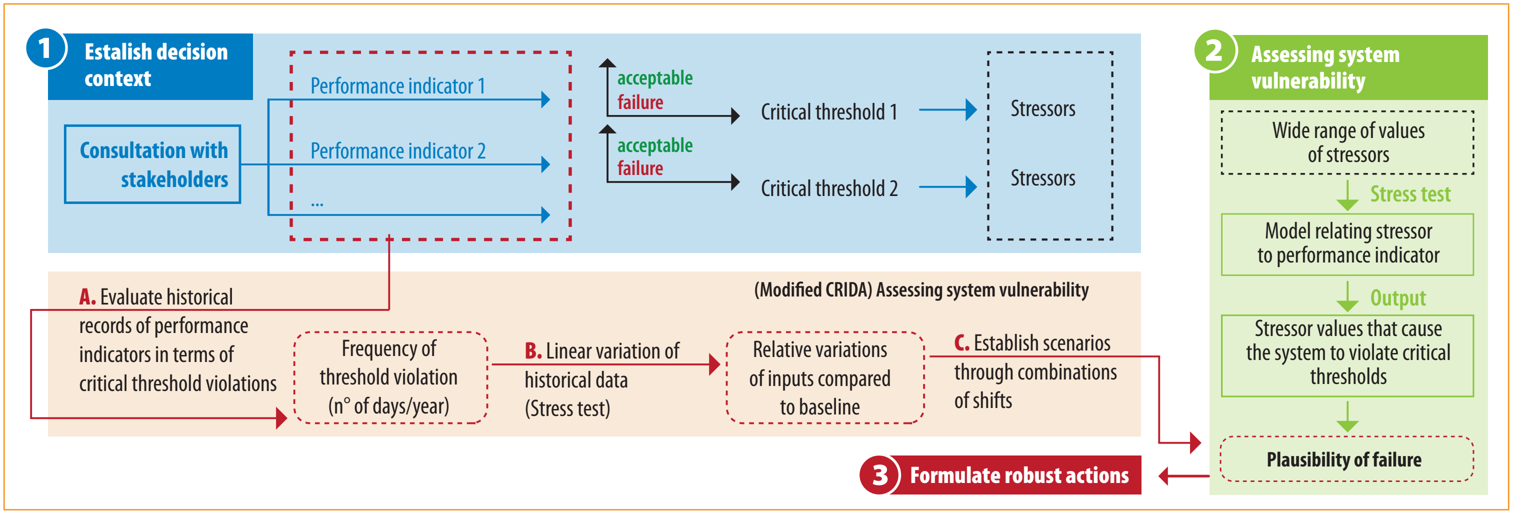

Figure 2

Methodology of the study in comparison to the CRIDA framework. The blue box, green box, and orange box detail the first three steps of CRIDA respectively. he modified planning steps are placed within the gray box, outlined with red dashed lines and follow the red arrows. © Koh et al., 2022. Published by Elsevier B.V. CC BY 4.0

Through a stakeholder consultation with the MWA, it was found that streamflow, salinity, and turbidity are the key performance metrics of the water supply system. The Samlae intake station (station C55 in **Figure 3**) is 96 km away from the Gulf of Thailand downstream. Given the proximity to the sea, one of the issues experienced by the MWA is the backwater effect due to tides, leading to saltwater intrusion problems, especially during the dry season when there is reduced flow from upstream. To minimize the effects of salinity, there has to be sufficient flow from upstream to manage the inflow of saline water. The river flow is monitored at the Bangsai station (C29) and salinity at C55.

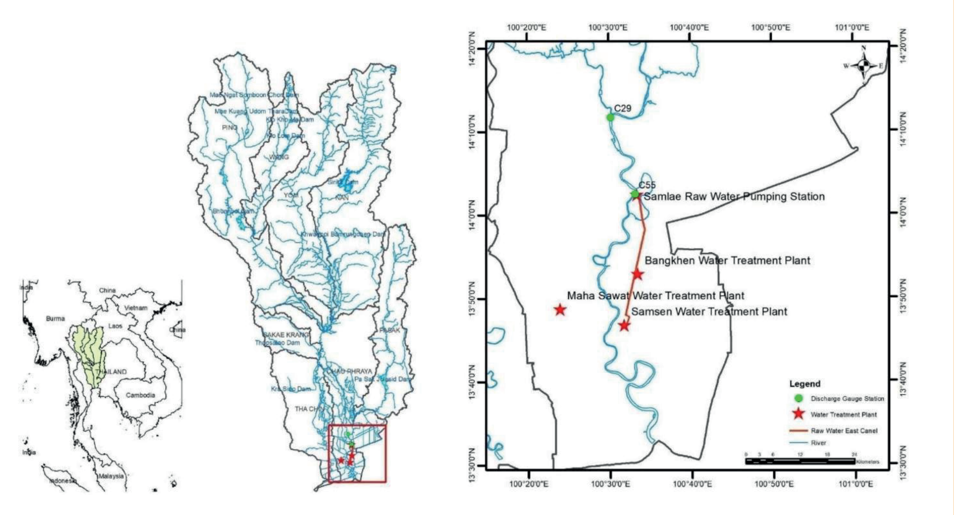

Figure 3

Map of Thailand, the Chao Phraya River Basin, and the study area. © Koh et al., 2022. Published by Elsevier B.V. CC BY 4.0

The following decision variables and thresholds form the basis of conducting the analysis (Koh et al., 2022):

(a) Salinity problems can occur when station C29 measures a river flow below 80 m^3/s. MWA will ask dam operators to release water from upstream to dilute salinity

(b) At station C55, salinity level of >0.25 g/L would cause the treatment plant to slow down operations, and a more severe level of 0.50 g/L would trigger critical plant operation plans.

(c) At station C55, a turbidity level of >200 NTU would increase the cost and duration of water processing.

Based on historical data (**Figure 4**), high salinity typically occurs during periods of low flow, and high turbidity during periods of high flow. The specific goals of the utility are, thus, to alleviate the salinity problems at the intake point during the dry season, and the turbidity problems during the wet season. The actions pertaining to such situations are illustrated in **Figure 5**.

A series of stress tests was conducted by exposing the system to a wide range of future conditions of the variables in the face of climate impacts. By varying the observed time series of data, the variability of the stressors was accounted for. Frequency curves derived through introducing scenarios of potential changes in the metrics will allow MWA to understand the consequences of variations to plan for impending risks, thereby improving the robustness of the water supply system. Based on the results, it is not possible to entirely mitigate the problem of high salinity. With current salinity levels, even if flow was increased by 50%, there will still be about 35 days of failure in a year. Having such drastic increases in flow will, on the other hand, make the system more susceptible to flooding and turbidity problems.

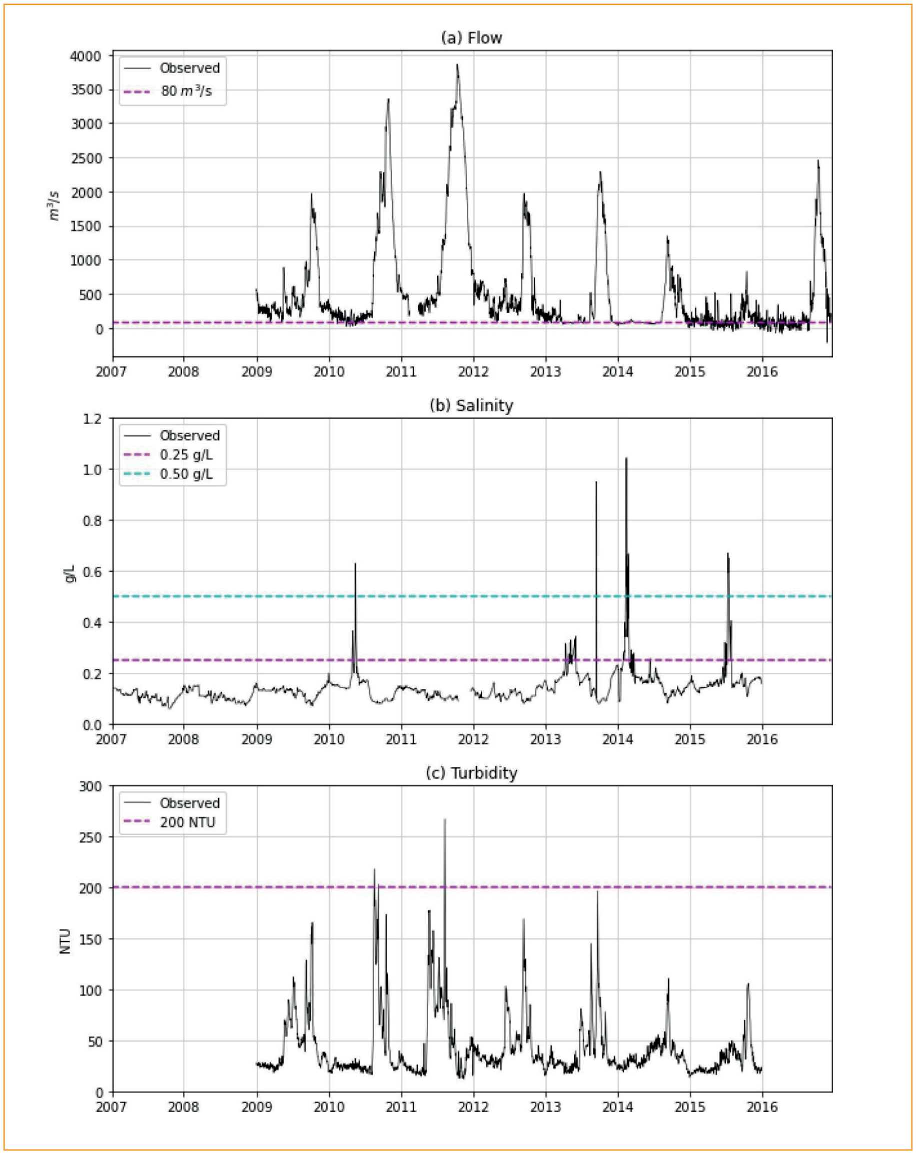

Figure 4

Average daily (a) flow at station C29, (b) salinity at station C55, and (c) turbidity at station C55. The dashed lines indicate the threshold(s) defined for each variable. © Koh et al., 2022. Published by Elsevier B.V. CC BY 4.0

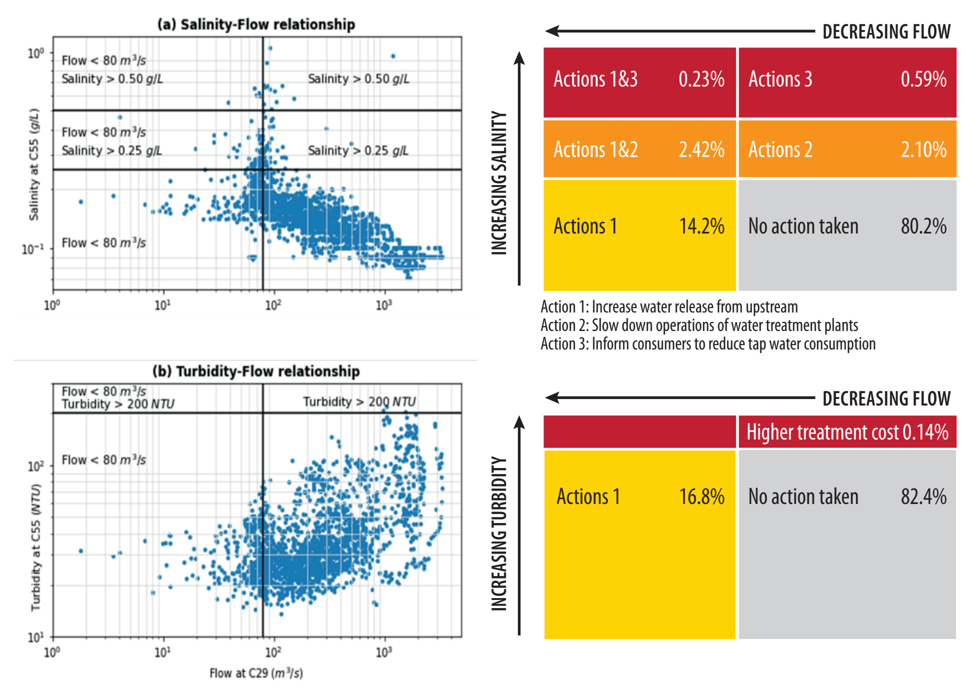

Figure 5

Left panel: Scatter plots indicating the relationship between (a) flow and salinity, and (b) flow and turbidity. Right panel: the corresponding schematic of actions taken in each case. Action 1 is increased water release from upstream. Action 2 is slowing the treatment plant's operations. Action 3 is asking consumers to reduce tap water consumption to preserve the salinity levels in their storage tanks. © Koh et al., 2022. Published by Elsevier B.V. CC BY 4.0

The approach used in this study suggests that the system is fairly robust to a wide range of plausible stressors given water allocation priorities. However, in the face of climate change, adaptation approaches can be explored if they can be shown to have more benefits than costs, contingent on the projected performance of the system. Proposed solutions include both operational and structural changes to the existing practices and water resources system. The sustainability of these solutions and their alternatives should be carefully evaluated, especially to justify the investments involved. For example, structural measures such as a salinity barrier may be needed to control the effect of salinity, which may require model-based analyses. Similarly, hydrological modeling of upstream watersheds to project river flows and a coupled hydrodynamic model downstream under climate change will help capture the complex dynamics of river flow, sea level rise, and sedimentation. With all these tools available, several more iterations of engagement with the stakeholders are necessary for developing Adaptation Pathways given the best information available. These fall under Steps Four and Five of the CRIDA cycle, which are currently being researched.

This case study was made possible with the support from the Asian Institute of Technology (Thailand), United States Army Corps of Engineers Institute for Water Resources (United States) and the Global Water and Climate Adaptation Centre: Aachen – Bangkok – Chennai – Dresden (ABCD Centre). The project was funded by the German Academic Exchange Service (DAAD).

Implementing Nature-Based Solutions in Udon Thani, Thailand to Adapt to Climate Change and Rapid Urbanization

Prepared by Guillermo Mendoza[1]

[1]US Army Corps of Engineers, Institute for Water Resources

Figure 6

Red Lotus Lake on the outskirts of Udon Thani serves as a popular tourist destination. © Georgios Kaleadis, Unsplash, 2018

Udon Thani, Thailand is a South-East Asian city that is expected to double in both physical size and population by 2030, largely due to its location as the entryway to South East Asia as an economic corridor part of the Belt and Road Initiative of the Chinese government. Udon Thani is experiencing increased frequencies of droughts and floods that are attributed to climate change, leading to concerns about stressing the water supply, particularly in the dry season, and increased flood impacts during the rainy season. These conditions place Udon Thani's vision to be an economic hub for the region and as a livable urban center at risk. This case study illustrates the application of a bottom-up approach using CRIDA in the development of a Green Infrastructure Master Plan for Udon Thani to address the impacts of climate change and rapid urbanization.

Through a U.S. Agency for International Development (USAID) project "Building Resilient Asian Cities in the Mekong region", the U.S. Army Corps of Engineers (USACE) was asked to support and "move the needle" towards a collaborative green infrastructure solution (USAID, 2014). A range of actions were taken to inform development of the city's master plan, focusing primarily around questions of the effectiveness, efficiency, acceptability, and completeness of potential adaptation and infrastructure solutions. The USACE incorporated the principles of its "Engineering with Nature" approach, which stresses the use of science, engineering, natural processes, and collaboration. On top of that, the planning process described in CRIDA was used to structure uncertainties around adaptation and development into a risk-informed decision making process.

Stakeholder engagement is central to the CRIDA planning process. In the case of Udon Thani, local stakeholder groups collaborated throughout, contributing to the development of landscape architecture renderings specific to stormwater management enhancement, site visits, conceptualization, and other input as a means to help decision makers and planners better understand conflicts. Three decision making workshops featuring participation of the mayor, senior city officials, various planning departments, and other stakeholder groups took place between 2015 and 2018 to come up with a shared vision for urban resilience and to discuss proposed design options and interventions for water supply and flooding concerns.

The CRIDA process incorporated a range of deep uncertainties into the analysis. These included rates of urbanization as well as changing intensities, durations, and frequencies of storm events.

To represent these drivers of change, "scenario bins" that integrated combinations of incrementally more stressful futures were developed collaboratively. As expected, greater resilience to a more extreme future (e.g., increasing floods and/or droughts) came at a higher cost. However, each incremental investment for flood resilience also contained greater ancillary social and environmental benefits, such as public space for cultural events or parks and recreation.

Political will is an integral part of enacting adaptation and development actions, and especially when it comes to ensuring the long-term success of a project. Highlighting the resilience benefits of various adaptation options led to more profound engagements with the public, mayor, and private sector stakeholders. This helped emphasize the strategic value of green infrastructure as a means for projects with immediate benefits to the public, and with real options for adaptability. As an outcome of the project, the city has committed to restore wetlands and develop green infrastructure solutions that integrate urban stormwater storage and diversion with recreation in the downtown area.

Udon Thani is in the implementation phase, taking action based on the outcomes of the CRIDA analysis. In the next phases of this work, adjacent peri-urban areas will be incorporated (**Figure 6**). A majority of urbanization is taking place in these areas, and a great deal of the city's stormwater runoff ends up there.

A more complete assessment of future risk of chronic failure in flood and drought management will be implemented in the near future as part of an iterative and collaborative process.

> “
>
> Political will is an integral part of enacting adaptation and development actions, and especially when it comes to ensuring the long-term success of a project.

Using Nature-Based Solutions for Flood Resilience in Guayaquil, Ecuador

Prepared by Luis Dominguez-Granda[1], Mijail Arias-Hidalgo[1], Heydi Roa[1], Carlos Rodriguez[1], Julio Torres[1], Daniel Sanchez[1], Jacqueline Sócola[1], Ad Jeuken[2], Reinaldo Peñailillo[2], Didrik Meijer[2], Florian Boer[3], Irene Seemann[4]

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[2] Deltares
[3] De Urbanisten
[4] Rebel Group

The delta city of Guayaquil, located in coastal Ecuador, has been declared the fourth most affected city in terms of economical loss (in comparison with its Gross Domestic Product (GDP)) from flooding by 2050 (Hallegatte et al., 2013). With a population near 2.7 million people, during the last decade the city has been occasionally affected by flood events, resulting in detrimental impacts on property and daily life of its inhabitants. A study supported by Corporación Andina de Fomento Development Bank of Latin America (CAF) on the Vulnerability and Adaptation to Climate Change for Guayaquil (I Care Environnement, 2018) reported that flooding is and will be the major challenge for the city when it comes to climate change. In the same study, the Febres Cordero (FC) parish (**Figure 7**) was identified as one of the most vulnerable regions, especially due to its high population density (24,175 inhabitants/km^2), poverty rates of near 20%, and limited access to public health care. Biophysical conditions exacerbate its vulnerability to floods, with nearly 80% of its perimeter surrounded by the Salado Estuary and its high level of impermeabilization resulting from a long history of informal urbanization (**Figure 7**).

Figure 7

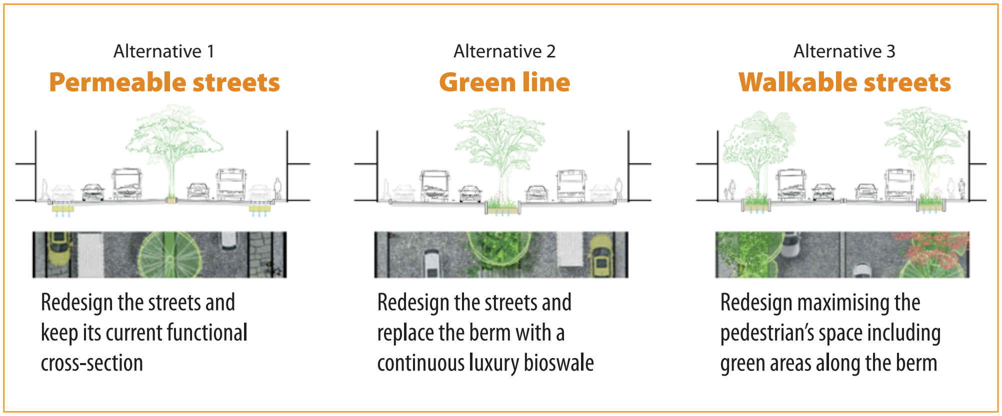
The Febres Cordero Parish, surrounded by the Salado estuary. The high level of impermeabilization can be observed where limited green areas are available within the urban limits.
© Google Earth Imagery & Maxar Technologies, 2021

This urban area of the city was selected for a pilot study aiming to evaluate the opportunities of NBS as a strategy to enhance flood resilience at the delta city of Guayaquil. For this, the CRIDA methodology was adopted by an international project consortium established by the Dutch institutions Deltares, Rebel, and De Urbanisten, as well as ESPOL (a public university in Ecuador). The project, supported by the Dutch program Partners for Water and the Municipality of Guayaquil, implemented the CRIDA methodology with a bottom-up and collaborative process involving societal actors and local governmental institutions. Problem analysis of floodings as well as the common vision for the future of FC parish were analyzed and defined in a July 2018 workshop with the participation of local societal leaders and governmental institutions related to water management, environment, urban planning, and risk management (**Figure 8**).

Complementary to traditional gray infrastructure for flood management, a “green” approach was accepted by workshop participants as an innovative multi-objective strategy aiming to enhance the parish´s flood resilience while generating other benefits such as recreational areas to support biodiversity and the well-being of the local communities.

Figure 8

Institutional workshop to construct a common vision of the future for Febres Cordero. Innovative Flood Management alternatives based on NBS are evaluated and ranked. © De Urbanisten, 2018



Alternative 1

Permeable streets

Redesign the streets and keep its current functional cross-section

Alternative 2

Green line

Redesign the streets and replace the berm with a continuous luxury bioswale

Alternative 3

Walkable streets

Redesign maximising the pedestrian's space including green areas along the berm

Figure 9

Proposed alternatives to redesign the urban public space with low-, mid- and high level of intervention. © De Urbanisten, 2022

A bottom-up vulnerability assessment was developed characterizing the threat imposed by urban flooding under selected climate change scenarios (i.e., emerging precipitation patterns and sea level anomalies). An urban flood model was built based on available information on terrain and stormwater drainage system characteristics. A combination of return periods of precipitation of 1, 10, 50 and 100 years and rainfall durations of 3, 5 and 18 hours were employed to generate flood maps. Sea level anomalies were also considered in model scenarios to assess the impact of sea level rise on drainage capacity of the existing stormwater network.

National Census data as well as door-to-door interviews with FC inhabitants were employed to map the socio-economic conditions and variability of the parish to support the social, economic, and physical vulnerability assessment. Interviews and workshops were also employed to assess the perceived economic impact of flood events of different intensities in commercial and residential areas. Economic losses in residential areas were estimated to be between USD $298 and $333 per home, resulting from flood levels of 20 cm and 50 cm respectively. In commercial sectors, economic losses were perceived to be between USD $29 and $41 per commerce under the flood levels previously described.

In the city, flood management improvements are usually associated with the expansion of the drainage capacity of existing stormwater networks. Nevertheless, based on the common vision of a greener FC parish and the need for a flood-resilient city, a set of NBS options were explored to contribute to flood management actions already implemented in the different areas of the parish. The NBS options presented included a well-known set of green and blue measures aiming to enhance water infiltration and retention to enhance flood resilience in urban environments. A group of these measures were incorporated within a set of three alternatives to redesign the public space in FC parish, involving a low-, mid-, and high-level interventions (i.e., from gray to green) (**Figure 9**).

These alternatives were presented for analysis to societal and institutional actors during workshops, where extension of flooded areas and flood drainage time were used as performance metrics to assess improvements towards flood resilience.

From the three presented alternatives, the design involving mid-level interventions on the public space was selected as the best compromise course of action by local governmental institutions and societal actors. Municipal departments with expertise in transportation and traffic, green spaces, public works, and stormwater management validated the feasibility of the proposed actions with existing plans for urban development for the coming decades. This stakeholder validation demonstrated that innovative solutions to enhance flood resilience can be compatible with existing urban infrastructure and municipal planning.

The participatory process enhanced the possibilities and likelihood of the adoption of proposed actions, as well as the institutionalization of the CRIDA approach through an inter-departmental and multi-institutional collaboration towards a more resilient city.

This case study was made possible with support provided by the Partners for Water (Netherlands) and the Municipality of Guayaquil, as well as the active participation of water risk planning-related institutions and community leaders who contributed to the project.

Developing an Indicator-based Sustainability Assessment Framework for River Basin Management in Iran

Prepared by Mojtaba Shafiei[1]

[1]East Water and Environmental Research Institute (EWERI)

Mashhad Basin is one of the critical basins located in the North East of Iran, with a semi-arid climate and a heavy reliance on groundwater resources (**Figure 10**). The surface area of Mashhad Basin is around 16,000 km^2, receiving approximately 250 mm of annual precipitation. The Mashhad Basin faces several serious water-related challenges to its sustainability, including high rates of groundwater depletion, land subsidence, transboundary water supply management, an increasing population, and other socio-economic problems related to competing water demands.

Figure 11 shows how an indicator-based assessment framework can play an important role in communicating scientific and technical information among different groups of stakeholders. In the context of sustainable water management, the belief is that an indicator-based sustainability assessment framework developed in a participatory manner can effectively contribute in narrowing the knowledge gap between those who analyze (researchers) and those who decide (policy makers). It is worth mentioning that an indicator is often defined as a qualitative or quantitative measure of a condition

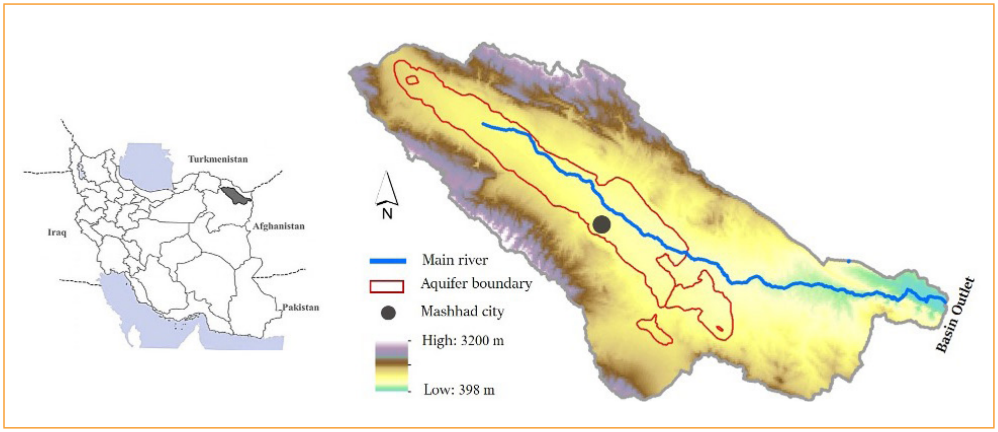


Figure 10
Location of Mashhad Basin in North East of Iran. © Elsevier, Ltd., 2022

of any phenomenon or particular issue. An index represents an aggregation of weighted indicators that represents collective preferences.

This project was a first attempt at providing a framework to measure the basin sustainability while involving key stakeholders through a participatory approach to build a general agreement on the goal of sustainable development at a basin level. As water management at the basin level needs a strategic long-term vision of how it would be shaped and function in 20 to 50 years, the methodology of the study involved a strategic planning process. An expert panel of relevant stakeholders was formed.

Most steps in developing a sustainability assessment (SA) framework were undertaken based on the consensus among the water-related stakeholders convened. **Table 1** shows the main goal (vision) and objectives of developing the SA framework.

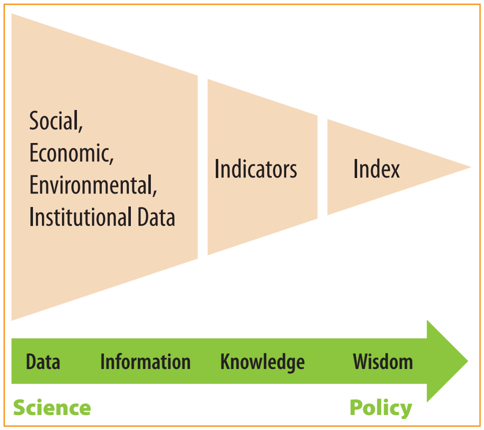


Figure 11
Translation of different data and information into policy making by developing indicator-based sustainability assessment framework. © Elsevier, Ltd., 2022

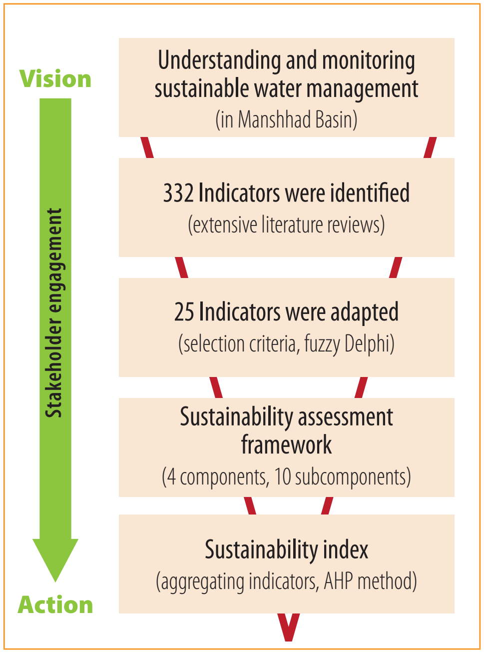


Figure 12
The process of developing the sustainability assessment framework of Mashhad Basin. © Elsevier, Ltd., 2022

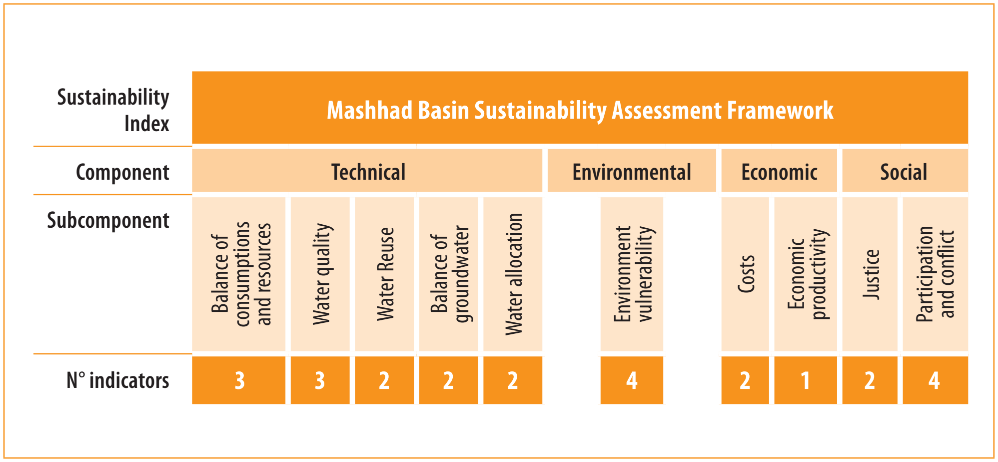
Table 1
Main goal and objectives of the study with their relevant beneficiaries in Mashhad Basin. © Elsevier, Ltd., 2022

Main goal: Monitoring the sustainable management of water resources in Mashhad Basin by developing an indicator-based assessment framework		
Objective	**Main Beneficiary (End-user)**	**Relation to the indicator-based SA framework**
Understanding sustainability issues in the Mashhad Basin and supporting sustainable solutions	Researchers, technical experts	Using different indicators and analyzing their variations along time
Measuring sustainability of actions, programs, and policies	Decision makers, policy makers	Using different indicators and developed index or indices
Evaluating the status/progress of the Basin sustainability	General public and media	Using the final developed sustainability index

Figure 12 shows the methodology for developing the SA framework and constructing the sustainability index for the Mashhad Basin. Within this process, 332 potential indicators were derived from existing literature. Using selection criteria and two-rounds of the fuzzy Delphi method, 25 fit-for-purpose indicators relevant to sustainable water management in the Mashhad Basin were identified. Subsequently, the SA framework was developed by categorizing final indicators into four main components (Technical, Environmental, Economic, and Social) and ten subcomponents to provide better links and insights of the basin water management practices between different groups of stakeholders.

Finally, using a weighting scheme through the Analytical Hierarchy Process (AHP), the sustainability index was constructed by aggregating the indicators. **Figure 13** shows the structure of the Mashhad Basin sustainability assessment framework.

Finally, **Figure 14** shows the results of applying the SA framework in the Mashhad Basin. The left-hand figure shows the results of scores for the ten subcomponent indexes. Subcomponent-related indexes are the results of aggregating indicators in each of the component categories. The right-hand figure shows the final sustainability index, which is based on the aggregate scores of all indicators combined into one measure. Additional details about the framework and scoring mechanism can be found in Shafiei et al. (2022). Results from this exercise indicated that the Mashhad Basin is in a critical unsustainable condition, with a sustainability index of 0.34 out of 1.



Sustainability Index	Mashhad Basin Sustainability Assessment Framework									
Component	Technical					Environmental	Economic		Social	
Subcomponent	Balance of consumptions and resources	Water quality	Water Reuse	Balance of groundwater	Water allocation	Environment vulnerability	Costs	Economic productivity	Justice	Participation and conflict
N° indicators	3	3	2	2	2	4	2	1	2	4

Figure 13

The hierarchical model of the Mashhad Basin sustainability assessment framework. © M. Shafiei, 2022

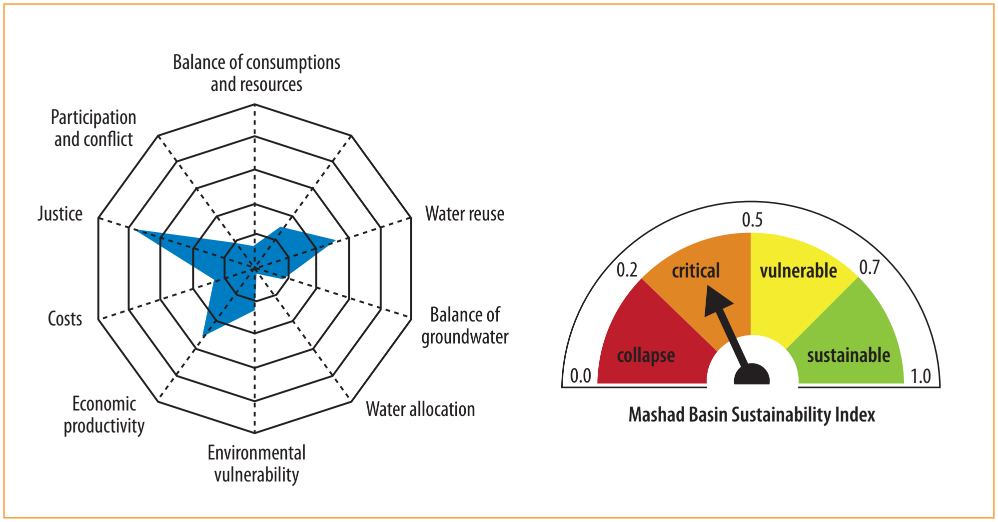


Figure 14

The sustainability assessment results of Mashhad Basin, based on 10 subcomponents' indexes (left) and the final sustainability index (right). © Elsevier, Ltd., 2022

To conclude, several findings came out of the project. Engaging stakeholders in the process of indicator development had a number of benefits including: 1) ensuring the applicability of a final framework for different end users as a policy/decision support tool, 2) serving as a learning process to help develop a better understanding of the practical concepts around basin sustainability with local perspectives, and 3) promoting a sense of ownership through a participatory process, thereby increasing the stakeholders' willingness to share their data and information.

The developed set of indicators, subcomponents, and components in this study can be used to inform policy and decision making in water management practices in terms of analyzing sustainability tradeoffs, thereby increasing transparency and accountability in the decision making processes. The SA framework developed in this study can support monitoring and achieving the SDG6 targets at the river basin level (i.e., as an SDG localization framework), particularly around SDG6 Target 6.B (Stakeholder participation).

Co-producing Knowledge on Drought Resilience for India's Devnadi River Basin

Prepared by Shuchi Vora[1]

[1]Global Resilience Partnership

The Devnadi River originates from the Aundhepatta hills of the Sahyadri mountains. The river basin is 560 km² (56,000 ha) in area and lies in the Nashik District in Maharashtra, India. The 70-km long spring-fed Devnadi River forms the source of the Godavari River, an important body of water that flows along 1465 km across four states in peninsular India. The Devnadi River Basin supports 150,000 people who mainly pursue agrarian livelihoods. Farms in the area produce onion, grapes, wheat, soya bean, varieties of millets, oilseeds, and lentils.

Farmers' landholdings are mostly less than 2 ha, with crops such as onion, sugarcane, etc. grown in the region. The Indian state of Maharashtra has a history of watershed management interventions with the intention of improving drought resilience of communities and agricultural water security in the region. However, droughts affect both humans and ecosystems, and resilient ecosystems are necessary precursors to drought-ready or resilient communities.

Droughts occur due to a combination of drivers such as natural climate variability, climate change, and human influences. Efforts are underway to understand drought and drought-like phenomena better globally, and thus, be able to manage the risk of droughts in a proactive manner. Moreover, proactive planning of droughts requires a systemic perspective to drought risk that takes into account not just the impact of the hazard, but the exposure to the risk, the adaptive capacity of people and nature, and the impact of the drought risk. This approach towards proactive drought planning has been well-documented in literature.

However, this approach requires a paradigm shift in the mental models of all stakeholders towards systems thinking. The consideration that droughts affect socio-ecological systems

Figure 15
Systems Thinking workshop on drought risk for the Devnadi River Basin. © S. Vora, 2019

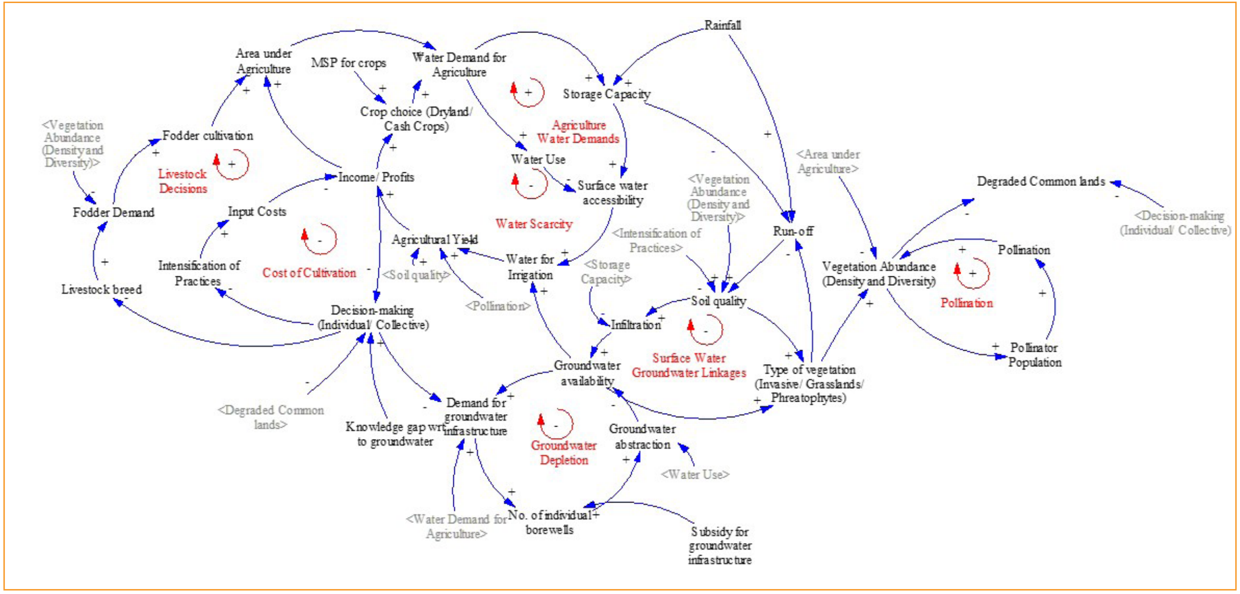


Figure 16

Causal Loop Diagram for Devnadi River socio-ecological system. © S. Vora, 2019

and interventions should be made keeping in mind that the interactions of humans and nature is crucial to executing proactive planning for droughts.

In June 2019, a Systems Thinking workshop was conducted using Group Model Building Tools in System Dynamics to co-produce knowledge on drought resilience futures for the Devnadi River Basin (**Figure 15**). Community representatives as well as relevant management partners were all part of the workshop. Subsystem feedback loops were generated, then converted to a qualitative Causal Loop Diagram shared with the participants (**Figure 16**). It has been improved over multiple iterations based on the feedback from the participants.

While this workshop reaffirmed the need for systems thinking in establishing social-ecological resilience, the role of knowledge brokering in transforming collective action did not end there. The primary knowledge broker from the workshop had to continue reinforcing systems thinking approaches and ideas through regular touch points, reviewing plans and monitoring implementation.

There were some important learnings from this project that can be shared with the conservation and water management community. Firstly, knowledge brokering as a role is under-appreciated, but transformations happen when partnerships can be brokered through tools for knowledge co-production. Further, for social-ecological resilience, the

Figure 17

Field learning with local community members and stakeholders in the Devnadi River Basin. © S. Vora, 2019 process is as important as the outcomes — being agnostic to the solutions and choosing instead to focus on the process of collaboration and co-production to co-create resilient futures for these drought-hit communities. In this act of co-producing drought resilience interventions, it was useful to recognize the importance and shortcomings of both traditional as well as modern knowledge systems. In doing so, the project attempted to create new adaptation actions that did no unintended harm, were systemic, and were co-owned by communities (**Figure 17**). Finally, this problematization using a systems thinking approach helped surface and address tensions in disciplinary trainings, values, world views, and mental models, thus truly breaking silos.

Based on this process of co-production, the partners have adapted the following solutions to enhance resilience of the Devnadi River Basin and its people:

- Multi-criteria prioritization of vulnerable villages to use scarce resources
- Capacity building of Bhujal Jankars (groundwater knowledge-keepers) and village leaders on participatory groundwater and ecosystem management using specially-created modules
- Drought Resilience Plans to help communities cite watershed solutions in areas of most need, conserving their springs while prioritizing water use management tools like crop-water budgeting and ensuring water security collectively at the village level.

Comprehensive Resilience Building in the Chimanimani and Chipinge Districts in Zimbabwe

Prepared by Alex Mauroner[1] and Koen Verbist[2]

[1]Alliance for Global Water Adaptation
[2]UNESCO Intergovernmental Hydrological Programme

Zimbabwe is exposed to multiple weather-related hazards, suffering from frequent periodic cyclones, droughts, floods, and related epidemics and landslides. On 15 March 2019, Tropical Cyclone Idai hit eastern Zimbabwe. At least 172 deaths were reported, more than 186 people were injured and 327 were missing, while over 270,000 people were affected across nine districts, particularly in Chimanimani and Chipinge. Water supplies were negatively impacted, with boreholes destroyed and other resulting water, sanitation, and hygiene (WASH) issues prevalent. Ecosystem damage also occurred where boulders and mud were dumped downhill, affecting wildlife habitats, water quality, tourism activities, and usability of land resources (**Figure 18**). The cyclone's aftermath has increased environmental risks, which will in turn affect local adaptation. Loss of vegetation cover means the natural defense against future flood waters and landslides

Figure 18
Evidence of landslides resulting from Cyclone Idai and loss of vegetation in the Chimanimani District.
© UNESCO BE-RESILIENT Program, 2021

is no longer available. Similar events in the future are therefore likely to cause even more destruction.

Beginning in early 2021, UNESCO commenced a project to reduce the vulnerability of communities in the Chimanimani and Chipinge Districts to natural disasters, such as floods, droughts, and landslides, and to enhance water resource management as well as ecosystem services in response to the uncertainty of future climate change. The project was designed to approach water-related risk and vulnerability through an integrated strategy that targets several aspects of DRR, and provides scalable implementation through the use of the CRIDA methodology.

The first phase of the project aimed to more clearly identify disaster risks through mapping of flood and landslide hazards as well as their impacts on specific areas of concern such as livelihoods, schools, and road infrastructure — all of which were particularly hard-hit by Cyclone Idai (**Figure 19**). Information on expected flood events was developed to identify flood hazard zones and potential evacuation routes that are required to strengthen emergency response capacities and to mitigate the impact of large flood events. Impacts were assessed through the use of Deltares' open-source Flood Impact Assessment Tool, providing insight into the physical exposure of communities to flood hazards in the regions of analysis. Landslide susceptibility maps for the two districts were complemented by more in-depth local assessment and field visits, which resulted in the identification of the main drivers of the landslides as well as the hotspots of landslide risk to human settlements, leading to a list of potential actions that could be considered to address these risks.

There is a general acceptance of the need to integrate climate change into medium- and long-term water resources planning, which is being hampered by the large uncertainty associated with climate change projections. As a response to this, the project integrated the CRIDA methodology to develop a medium-to-long term water and environmental vulnerability assessment. The first three steps of CRIDA (out of five) were undertaken in the project area.

Through an active stakeholder engagement process involving a workshop with diverse local participation (**Figure 20**), a problem statement of the main issues and concerns to be addressed was defined (Step 1) for water security and environmental impact in the area. Participation in the process involved local and regional government representatives, community and tribal leaders, industry representatives, and environmental civil society organizations brought together to identify potential indicators and thresholds. This process was followed by a technical climate stress test (Step 2) to identify expected climate change impacts on water resources, as well as to provide a framework to evaluate the effectiveness of adaptation strategies. Outputs from the stakeholder workshops provided the specific social, economic, cultural, and environmental performance measures against which the climate stress test would track impacts. As part of CRIDA's Step 3, stakeholders were consulted to identify and prioritize adaptation actions and to provide inputs to build an Adaptation Pathway for the area (i.e., potential adaptation options to be explored as future conditions change).

Figure 19

A hillside community in the Chimanimani district. © UNESCO BE-RESILIENT Program, 2021

As a result of these efforts, local decision makers and project partners identified an initial nature-based intervention aimed at reducing disaster risk and promoting adaptation to climate change in the region, all while supporting socio-economic development and livelihoods. Stress tests were run to assess large centralized dams versus decentralized check dams, evaluating impacts on risk reduction, as well as co-benefits and (negative) impacts on ecological systems using a multi-criteria analysis. As a result, sixty check dams are now being constructed across the project region to reduce flood and landslide risk, while offering co-benefits of aquifer recharge to support agriculture and drinking water provision. Local communities are helping to build and manage the check dams, and to track impact on a number of ecological and hydrological parameters using a monitoring framework.

A flood and drought monitoring and early warning system was also put in place to support early action and increase early warning capacities. Through a disaster risk vulnerability assessment, the adaptive capacity of the communities was assessed to build a community-engaged early warning approach and work towards early action protocols. This is combined with improved communication through the setup of two community radios in the districts, as well as active community engagement in 10 wards in both districts.

Figure 20
Project partners work with local farmers to discuss disaster impacts and adaptation interventions around agriculture.
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Climate Change Adaptation for Municipal Water Supply in Colombo, Sri Lanka

Prepared by Upeakshika Bandara[1] and Mukand S. Babel[2]

[1]Regional Integrated Multi-Hazard Early Warning Systems (RIMES), Asian Institute of Technology
[2]Water Engineering and Management, Asian Institute of Technology

The global threat from climate change is immense and particularly challenging to water availability and access due to increased temperatures, rising severity and frequency of extreme events, and changes in seasonality (Mwadzingeni et al., 2022), which has led to extensive research on the topic. The traditional method of impact assessment is the top-down approach, which comes with high uncertainty as described in studies by Koh et al. (2022), Clark et al. (2016), Mendoza et al. (2015), Garcia et al. (2014), and Yao et al. (2011). Hence, relying on the findings of top-down approaches is challenging for important and expensive climate-related decisions. The CRIDA methodology follows a combined top-down and bottom-up approach for risk-informed decision making, where risks are assessed and communicated to decision makers and stakeholders (Mendoza et al., 2018). The present study used CRIDA to identify the impacts of climate change on the water supply of Colombo, Sri Lanka.

Colombo city, (area: 37.29 km²) with a population of 2.2 million (15% of urban population) is important for Sri Lanka's economy as 80% of industries are located here, contributing to 50% of the country's GDP (Li & Pussella, 2017). The Kelani River is their primary source of water and the Ambatale Water Treatment Plant (WTP), managed by National Water Supply and Drainage Board (NWSDB), is responsible for purifying over 500,000 m^3/day of water to provide clean water to the city (JICA, 2015). The Kelani River Basin has an area of 2,292 km^2 and experiences a hot and humid climate (Fayas et al., 2019). Rainfall mainly occurs during the South-West Monsoon from April to September (Abeykoon & Nawarathna, 2011). The basin has an average annual rainfall of 3,450 mm and runoff of 5,500 million m^3 with peak flows between 800-1500 m^3/s and low flow of 30 m^3/s (De Silva et al., 2014). **Figure 21** presents the details of the study area. Impacts of climate change on the Kelani River Basin (Dissanayaka & Rajapakse, 2019) put the water supply system at risk.

Figure 22 presents the methodology of the study, which follows the CRIDA approach (Mendoza, et al., 2018). The decision context was initially established, where stakeholders were involved to define the climate change risk. Twelve personnel from NWSDB were interviewed to identify the critical thresholds of the system. Then, the vulnerability of the water supply system to climate change was identified through a series of stress tests. Future climate and hydrology were obtained using RCMs (Regional Climate Models) and a hydrological model for the period 2030-2059. Based on future hydrology, the system was stressed to understand the likely failures. Finally, adaptation measures, particularly around demand management, were tested to analyze how the system would perform under reduced demand (Koh et al., 2022).

According to stakeholders, a major concern of the water supply system is the inability to meet demand. The main critical threshold of the system is the flow requirement at the intake 45 m^3/s, with per capita demand of 180 liters/day. If this threshold is not met, disturbances on water supply would prevail. Failure of the system is represented by the number of days where the flow was below the critical threshold. NWSDB experiences a considerable number of failure days with insufficient production.

Future hydrology suggests that flow would likely increase. Accordingly, the system was stressed under increased demand scenarios as indicated in **Figure 23**.

With increased flow, the number of failure days decreased overall, though a considerable number remained. Dry months (December) showed higher failure, but the highest failure occurred in April which is outside of the present dry season. **Figure 24** shows how risk of failure was defined, where scenario I has moderate to high risk while high and very high risk were observed for scenarios II and III.

Demand management as an adaptation measure was tested under three scenarios based on Dawadi & Ahmad (2013). **Figure 25** presents the per capita demand, relevant thresholds, and change in risk under these scenarios. A rapid decrease in demand is seen under scenario A, with risk being moderate to high. Scenarios B and C show that reduced demand could be a solution to shift the risk from very high to high or moderate and reduce the number of failure days.

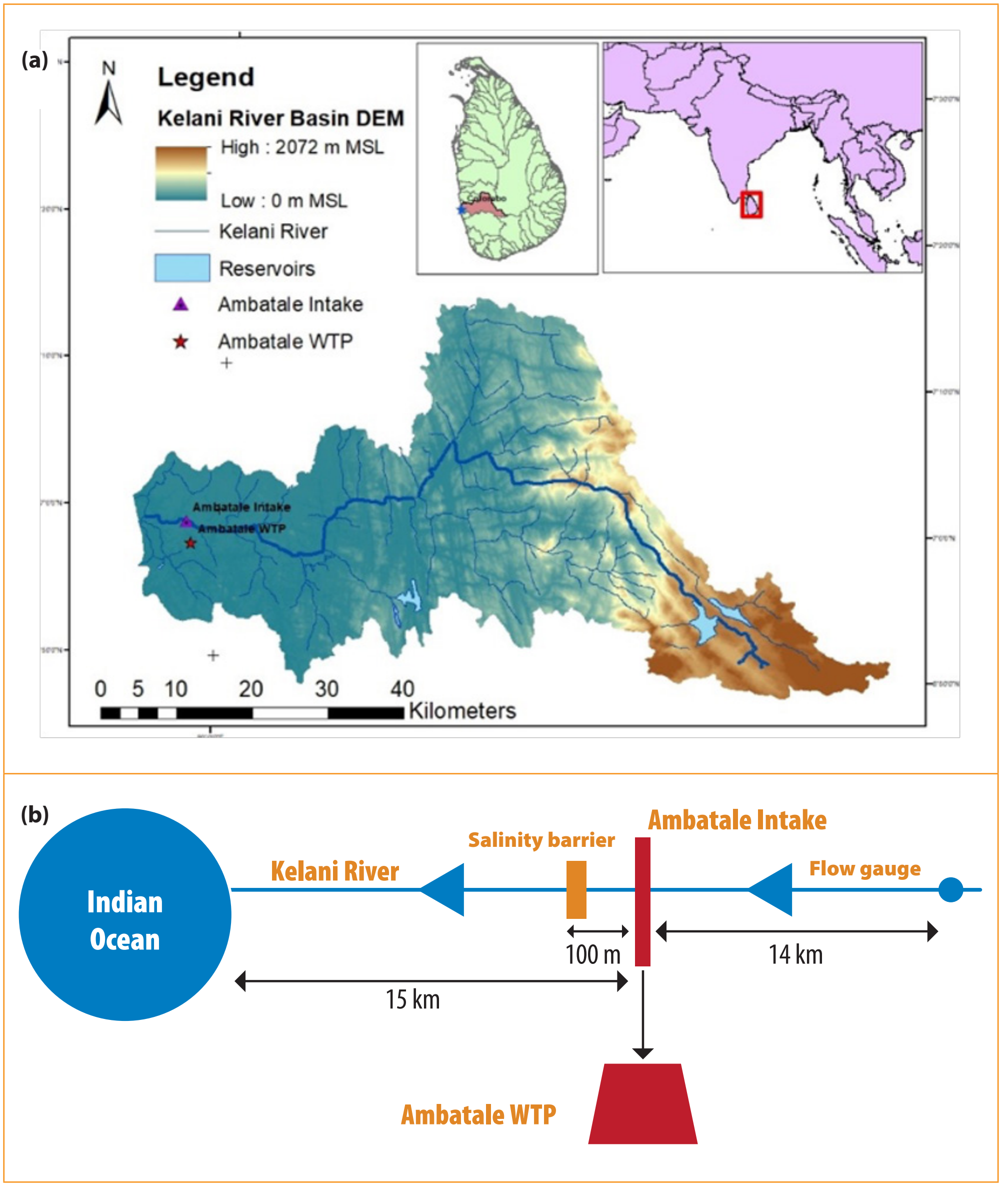


Figure 21

(a) Colombo city and Kelani River Basin and (b) schematic of water flow in Kelani River Basin. © Bandara & Babel, 2022

For no failure, per capita demand should be reduced to 69 liters/day. Drastic measures are needed to achieve such a feat. Some demand management measures include: programs for raising awareness (Addo et al., 2019; Manez & Cerda, 2014), limitation of supply through usage thresholds (Foster, 2010), water pricing (Ahmad et al., 2017; Calatrava et al., 2015), reduction of non-revenue water and relying on alternative sources (Farouk et al., 2021; Loftus, 2011), and water reuse to reduce stress on surface water (Molinos-Seante et al., 2011).

The case study showed that CRIDA is able to provide an effective methodology for the identification of climate risks on the adequate functioning of the hydrological system under climatic and demographic uncertainty.
The stress test indicated that although the future flow is likely to increase, failure will likely still occur due to a compound impact of hydrologic changes and population growth, as identified through the decision context by involvement of all stakeholders.

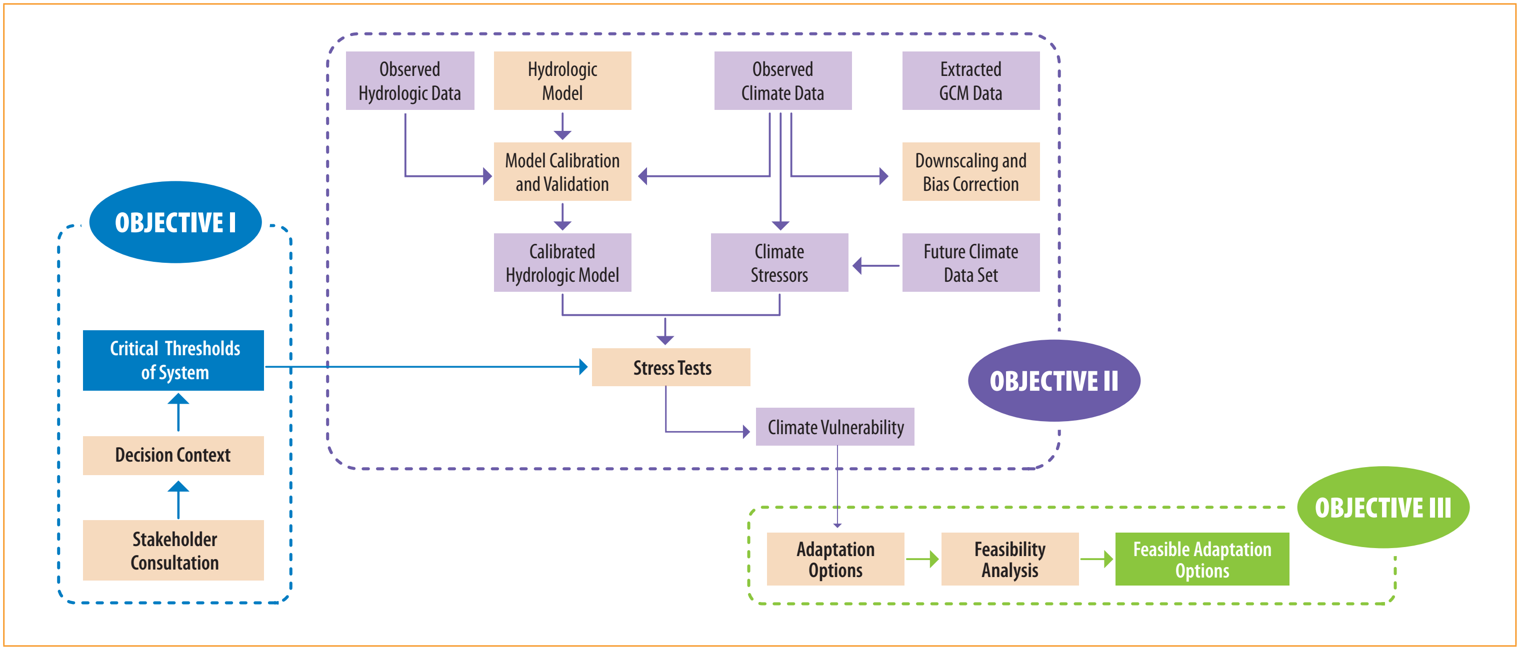
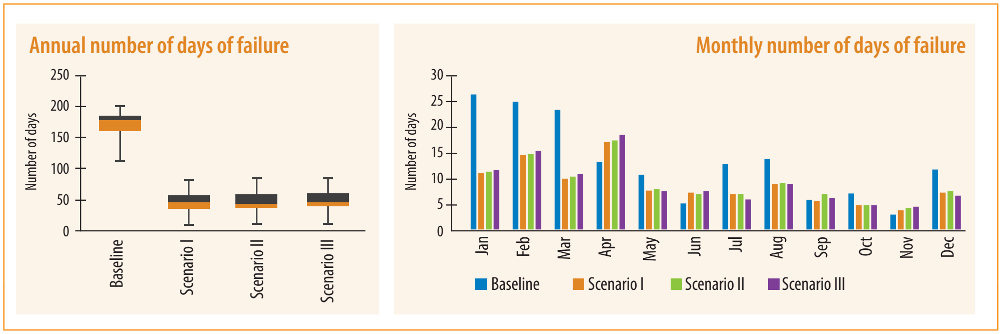


Figure 22

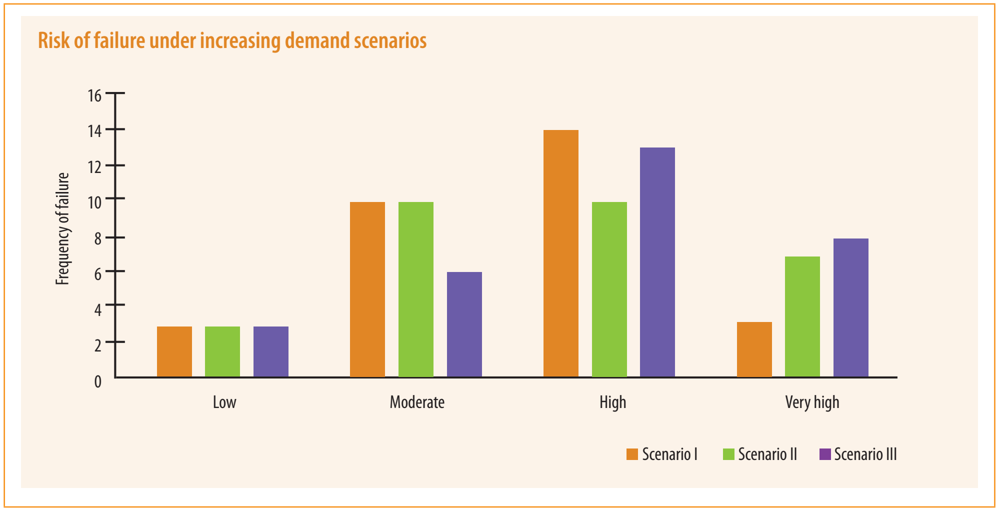
Overall methodology. © Bandara & Babel, 2022



Scenario	Per capita demand (l/day)			Minimum flow (m³/s)				
	2030-2039	2040-2049	2050-2059	2030-2034	2035-2039	2040-2044	2045-2049	2050-2054
I	180	180	180	47	49	50	51	52
II	220	245	269	51	52	55	56	60
II	241	277	313	52	53	58	59	64

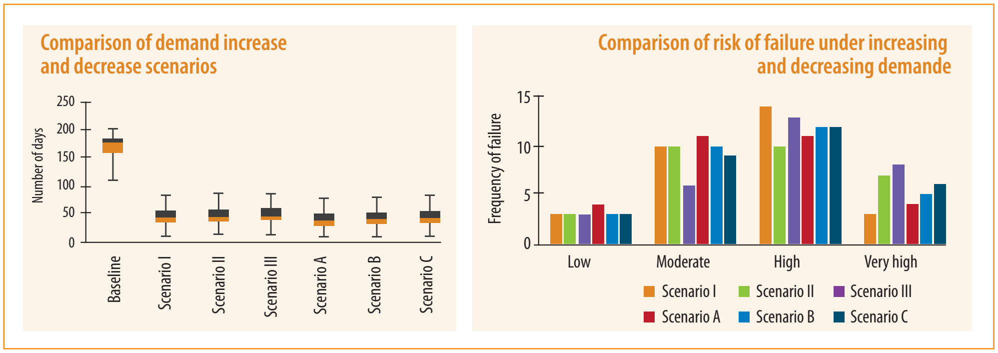
Figure 23

Per capita demand, minimum flow threshold, and failure under increased future demand for scenarios I, II, and III. © Bandara & Babel, 2022



Range (annual number of days of failure	Risk of failure
0 to 20	Low
21 to 40	Moderate
41 to 60	High
61 to above	Very high

Figure 24
Risk of failure under increased demand for scenarios I, II and III. © Bandara & Babel, 2022



Scenario	Per capita demand (l/day)			Minimum flow (m³/s)						
	2030-2039	2040-2049	2050-2059	2030-2034	2035-2039	2040-2044	2045-2049	2050-2054	2055-2059
A	162	144	126	46	47	47	48	47	47
B	180	162	162	47	49	48	49	48	49
C	198	180	180	49	50	50	51	50	51

Figure 25
Per capita demand and minimum required flow for demand decrease scenarios (A, B and C), and a comparison of changes in failure as well as risk between demand increase (I, II, and III) and decrease scenarios. © Bandara & Babel, 2022

Designing a Climate-Resilient Hydropower Sector in Nepal

Prepared by Divas B. Basnyat[1] and Dibesh Shrestha[1]

[1]Nepal Development Research Institute (NDRI)

The water resources and hydropower development of Nepal is of interest to South Asia as the river basins of Nepal form the headwaters of the Ganges River Basin. Hydropower complements other variable renewable energy sources, like solar and wind, and other multi-purpose uses of water; it further offers large benefits to local communities and national economic development. Hydropower will play a major role in the future energy mix, given that South Asia still has untapped hydro-potential and is committed to net-zero carbon emissions in the future. Hydro development in Nepal also provides opportunities for potential export to replace fossil fuel generation and balance variable solar/wind energy in India (with a current power mix of 58.6% coal/fossil fuel, 28.1% solar/wind/other RE, and 11.6% hydro) (India Ministry of Power, 2022), and Bangladesh (with a current power mix of 50.8% natural gas, 28.3% Heavy Fuel Oil, and 5.2% import) (BPDP, 2022).

Hydropower development, however, faces several challenges in adapting to future climate change and other uncertainties. The following case study demonstrates the use of a bottom-up climate risk assessment to adapt the hydropower sector to these uncertainties.

The variation of precipitation and temperature in the catchments of Nepali rivers, extending from China to India, is quite high as seen in **Figure 26** and **Figure 27**. Lack of infrastructure to manage the temporal and spatial variation in the climatic and hydrological regime of Nepal is a constraint for water resources development. The current climate variability and extreme events cause major impacts and economic costs to Nepal, estimated to be from 1.5% to 2% of the annual GDP, and is as high as 5% of the annual GDP in extreme years (IDS-Nepal et al., 2014). Future climate change and other regulatory uncertainties are expected to exacerbate these impacts, with economic costs to infrastructure development and livelihoods in the country (NDRI et al., 2017). The future climate change uncertainties are evident from **Figure 28** and **Figure 29**, which show the spread of the changes in the long-term precipitation and temperature projected by the different GCMs for the RCP 4.5 scenario in the future. In addition to climate uncertainty, the hydropower sector of Nepal faces non-climatic uncertainties like changing regulatory policies, tariffs, markets, cross-border trading, power mix, energy alternatives, and project construction time and cost over-runs.

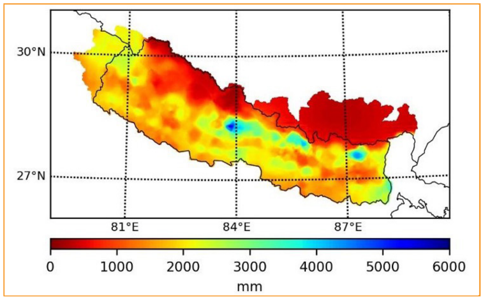


Figure 26

Variation of annual precipitation across the catchment of Nepal's river basins.
© Basnyat & Shrestha, 2022

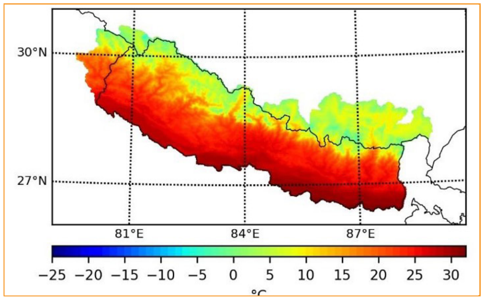


Figure 27

Variation of average monsoon (June–September) temperature in Nepal's river basins.
© Basnyat & Shrestha, 2022

Within this project, a bottom-up approach (**Figure 30**) was adopted to assess the risks of climate and other uncertainties and to design a resilient hydropower sector. The approach consists of three important steps:

Step 1: Vulnerability assessment using a Climate Risk Assessment (CRA) methodology

Step 2: Identification of adaptation options using the Adaptation Pathways approach

Step 3: Institutional analysis and identification of entry points and barriers to adaptation.

The CRA assessment started with stakeholder consultations to define the key performance indicators and the thresholds of acceptance. The performance indicators varied with the different stakeholders; private developers were more concerned about financial viability whereas policy makers were concerned about power system reliability, safety, design standards, and social and environmental safeguards. Stress tests were used to define the vulnerability domain in terms of performance and risks to current and future climate. This process was undertaken using a holistic system of weather generators, hydrological models, hydropower projections and system models, and economic models. Risks were assessed by determining the plausibility of climate conditions that lead to unacceptable systems performance. This led to identifying adaptation options using the Adaptation Pathways approach.

Finally, the mainstreaming of Adaptation Pathways was addressed through institutional analysis and identification of entry points and barriers.

The assessment showed that current climate and hydrological variability is a major challenge to Nepal's hydropower sector. Catchment location, elevation, and size largely influence the flow variability. The risk from future climate change uncertainty is higher in rain-fed catchments than in snow-fed catchments, and higher in smaller catchments than larger catchments. The greatest impacts of climate change are from extreme events leading to geo-climatic hazards, like landslides, landslide dam outburst floods, glacial lake outburst floods, flash floods, riverine floods, and debris flows. Impacts of extreme events on hydropower are two-fold: direct infrastructure damage, and losses on energy generation due to shut-downs and increased sedimentation. Besides, an increase in rainfall intensity results in a huge volume of sediments, and this can reduce turbine lifetime and increase operational downtime (when loads are high), thus increasing operations and maintenance costs and energy losses. Research at one hydropower plant indicated that an increase in sedimentation concentration (due to increased flow by 5-10%) can lead to a revenue loss of 10-20%.

The current power system suffers from an inefficient power mix, and projects designed under the current regime (pricing, market, and regulatory policy) will not perform as designed in future changes (uncertainty). Results show that adaptation to climate change is context-specific, and a portfolio of options (i.e., not one-size-fits-all) is needed.

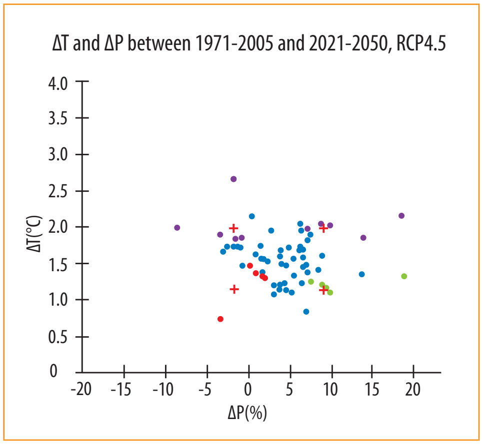


Figure 28

Spread of projected changes in Temperature (ΔT) and Precipitation (ΔP) of different climate models in Nepal. © Basnyat & Shrestha, 2022

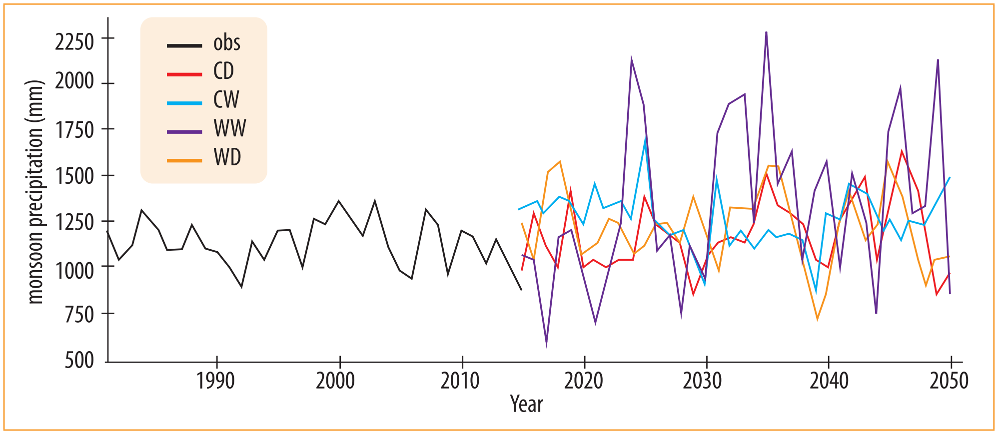


Figure 29

Projected changes in monsoon (June – September) average precipitation of Nepal. Note: CD, CW, WW and WD are representative climate models (CMIP5) for Cold-Dry, Cold-Wet, Warm-Wet and Warm-Dry conditions defined by the range of changes of temperature and precipitation in Nepal. © Basnyat & Shrestha, 2022

Adaptation Pathways for current and planned hydropower projects were outlined. For current hydropower plants, low-regret measures that address current variability and resilience for the future were recommended. This involves actions that improve performance or reduce risk at a low cost. Some examples are hydro-meteorological and early warning network establishment, powerhouse protection, turbine recoating, insurance, and other good practices. For the planned hydropower projects, emphasis was placed on climate-smart planning and design, ultimately leading to the recommendation of a phased approach instead of overdesign upfront. To prepare for future risks, emphasis should be placed on information (value) and learnings to inform future decisions.

Finally, entry points to mainstream adaptation were identified, which included: (a) mainstreaming climate factors in existing activities and policies (e.g., risk screening in design guidelines, system planning, Environmental Impact Assessment, power purchase agreements, dam safety, risk sharing) to make it climate smart, and (b) investment in learning (e.g., monitoring, research, and pilots) to improve future decisions. Following these recommendations, Nepali's hydropower sector can become more resilient to extreme events, long-term climatic shifts, and other uncertainties.

This case study is based on the work carried out at Nepal Development Research Institute (NDRI), initially during the project "Adaptation to Climate Change in the Hydroelectricity Sector in Nepal" in 2015-2016 as well as other follow-up studies. The initial project was led by NDRI in collaboration with Practical Action Consulting (PAC), Nepal and Global Adaptation Partnership (UK) Limited (GCAP). It was funded by Climate and Development Knowledge Network (CDKN), a project funded by the UK Department for International Development and the Netherlands Directorate-General for International Cooperation (DGIS), and was led and administered by PricewaterhouseCoopers, LLP.

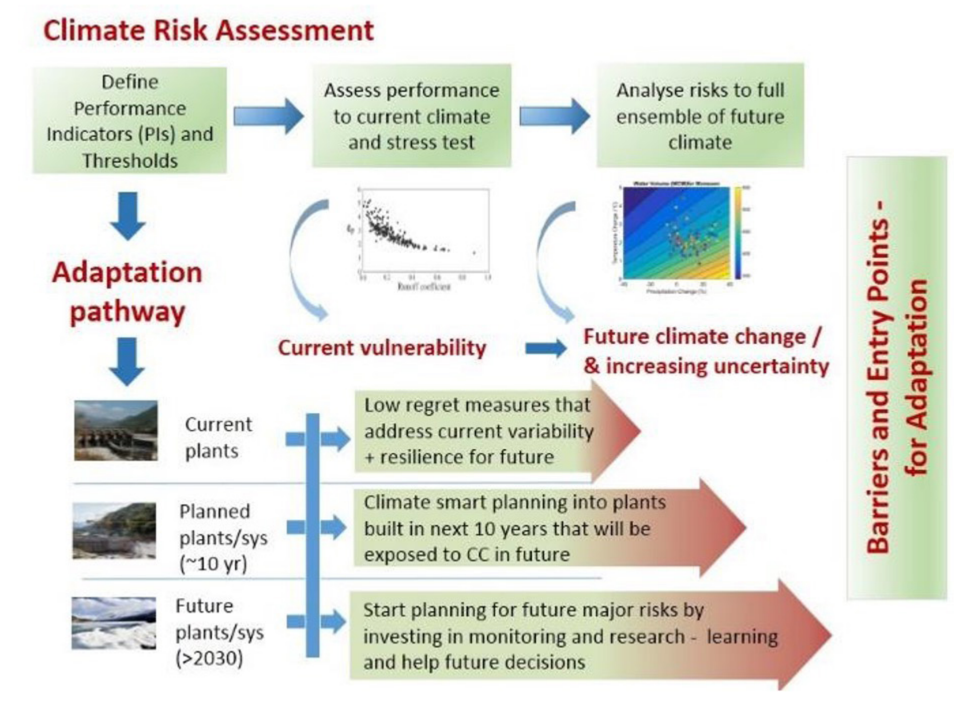


Figure 30
Climate Risk Assessment methodology used in the study. © NDRI, 2017

Resilient Water and Energy Supply for Zambia's Capital in the Face of Drought

Prepared by Marc Tkach[1] and Chipili Chikamba[2]

[1]Millennium Challenge Corporation

[2]Millennium Project Completion Agency

Lusaka, the capital city of Zambia, is in a drought prone region of southern Africa. The two million residents are dependent on a network of shallow aquifers and the Kafue River, the latter providing 40% of the city's water supply. Additionally, the city's power grid is wholly dependent on water through regional hydropower dams. This makes the well-being of Lusaka's inhabitants highly vulnerable to worsening droughts.

Lusaka's climatic future has arrived. A set of drought and governance circumstances from 2016–2018 led to rolling blackouts often exceeding 12 hours a day. Existing research implies that this drives up household costs and exacerbates public health challenges.

During this event, the Millennium Challenge Corporation (a U.S. Federal Agency) was funding a USD $354 million program of improvements in Lusaka's water treatment and delivery systems (**Figures 31-32**). This included the city's water treatment plant at the Kafue River, Iolanda (**Figure 33**). The severity of the power shortages heightened concern among the U.S. and Zambian program managers. They wanted to know if the plant could perform under worsening climatic conditions and if adjustments to design would lead to higher resilience.

Already in construction, the implementers sought a quick, inexpensive, and grounded analysis to make the investment more resilient to drought and robust to a warmer and drier climate. After considering many bottom-up solutions, the team settled on the use of the CRIDA approach with support from the U.S. Army Corps of Engineers Institute for Water Resources. CRIDA was selected because it accounts for situations with poor historical data, builds stakeholder credibility through widely understandable modeling, and provides decision makers a range of realistic and viable choices.

The team first sought to narrow the area of study. Was performance loss during a drought impacted more by lower river flow or loss of power? The Lusaka-based team was able to aid the US-based analysts in collecting the available data and networking with affected stakeholders. Analysis demonstrated that energy availability was the limiting factor. It takes a lot of power to pump 90,000 m^3/day over 50 km to Lusaka's city storage. Concern over water availability was resolved because analysis demonstrated that

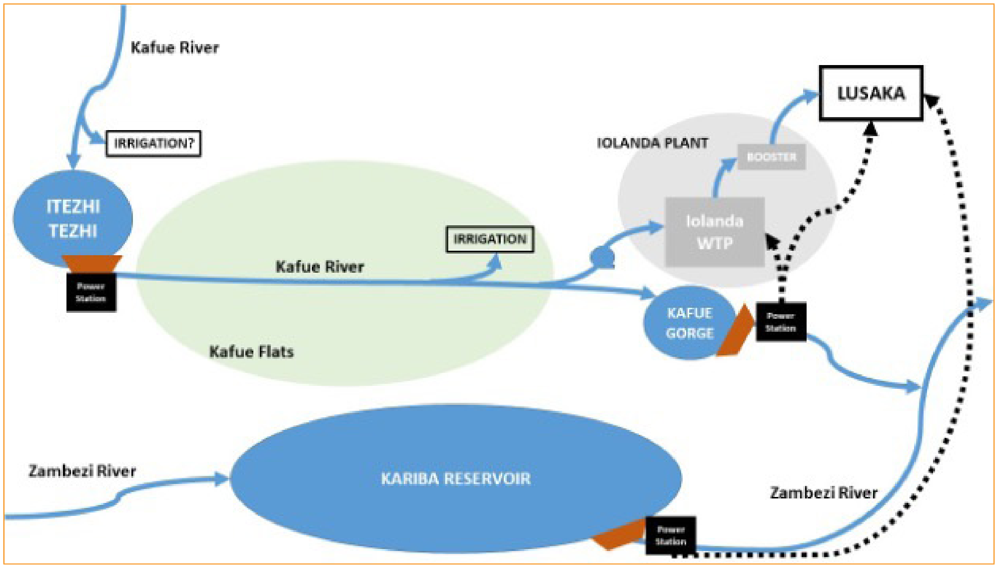


Figure 31

A model of the water supply and energy systems around Lusaka, Zambia. © Tkach & Chikamba, 2022 the abstraction wells were sufficiently deep to mitigate drought conditions. This finding quickly focused the team on obstacles and solutions to energy provision.

The next step included setting a risk analysis weighing analytical uncertainty and severity of impact. Since this project had low data availability and high impact on the community for even minor drops in performance, CRIDA recommended a strategic approach of flexible and robust solutions (**Figure 34**). That means solutions that can be scaled and adjusted as conditions changed and more was known.

This led to developing and modeling solutions that reduced the time the plant could not meet its base requirements. Three solutions were modeled:

1. expanding the city's storage capacity
2. providing diesel generation to the high lift pump sets
3. entering into a dedicated power agreement with the power utility to prioritize the plant's operations during power outages.

Using Incremental Cost Analysis, by comparing the solutions to a range of future scenarios built from global climate models, the team was able to link cost to future robustness of the Iolanda plant. It was learned that providing diesel generators and a dedicated power agreement (already being pursued) was sufficient to mitigate shortages.

The results led to impact. It was not necessary to provide these generators now. Instead, it would be sufficient to amend the existing construction contract to build generator pads and connections to the high lift pumps.

Figure 32

Construction within Lusaka. © Tkach & Chikamba, 2022

Figure 33

Kafue Water Treatment facility. © Tkach & Chikamba, 2022

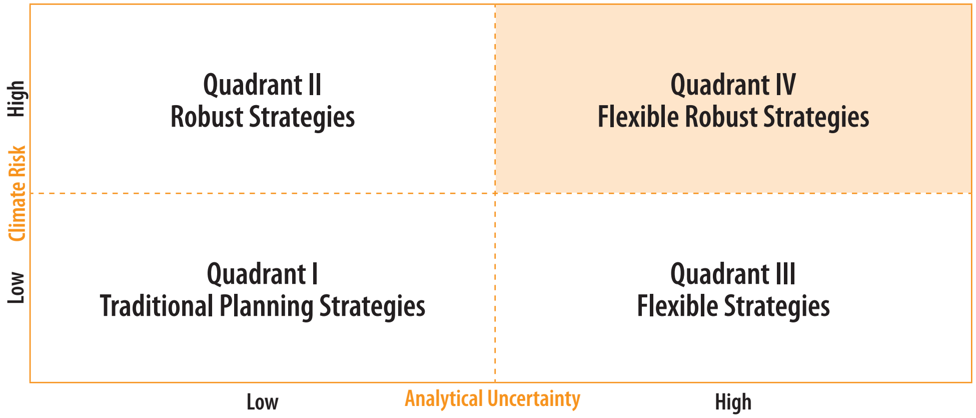


Figure 34

The Level of Concern matrix from the CRIDA approach. Adapted from © UNESCO & ICIWaRM, 2018, CC-BY-SA 3.0 IGO

The generators could be purchased by the utility consistent with their own budget planning policies. The cost was negligible for both solutions.

In summary, the implementation team was able to quickly diagnose and develop a substantiated solution using the CRIDA methodology in only a few months. The stakeholders including the donor, the implementers, and the asset owners were able to buy-in, understand, and proceed with viable solutions that would allow for continued delivery of service for the city even in the face of a changing climate.

This case study was made possible with the support of several parties involved in carrying out the work. The Millennium Challenge Corporation served as the infrastructure program donor. Millennium Challenge Account – Zambia was the executing agency. Technical assistance came from the U.S. Army Corps of Engineers Institute of Water Resources and ICIWaRM, who also served as the CRIDA study sponsor.

Climate Risk Assessment in Bolivia's Guadalquivir and Azero River Basins: A Bottom-up GIZ Approach

Prepared by Carlos Saavedra[1], Nicole Stuber[1], and Jose Luis Gutierrez[1]

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The global population is estimated to double by 2050. This has serious implications for the water availability and water demand across the LAC region, which is likely to increase from the current 15-20% of consumption to 30% regional water demand. Climate change is directly impacting the availability and scarcity of water (too much or too little water) across the Bolivian river basins in general, and specifically in the Guadalquivir and Azero River Basins (**Figures 35-36**). To create effective adaptation strategies and to deal with climate impacts on communities' livelihoods, it is important to identify the areas with higher climate risks based upon the best technical and social knowledge, while simultaneously identifying the capacity of social and natural systems to adapt. The direct impacts of climate change in the Guadalquivir and Azero River Basins include rising temperatures, changing precipitation patterns, and more acute drought and floods. However, the associated risks are highly influenced by the socio-economic, agricultural, and cultural contexts.

To address the water security challenge, the German Cooperation through the Integrated Rural Development at Basin Scale Programme (PROCUENCA) project implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) is mainstreaming climate change into the national water resources planning and strategic river basin management within the context of the National Water Resources Plan 2021-2025 (previously the National Watershed Plan 2006-2020). The GIZ climate risk approach was applied to diagnose the current and future vulnerability and measures designed for

Figure 35

Guadalquivir River Basin. © PROCUENCA GIZ Bolivia, 2022

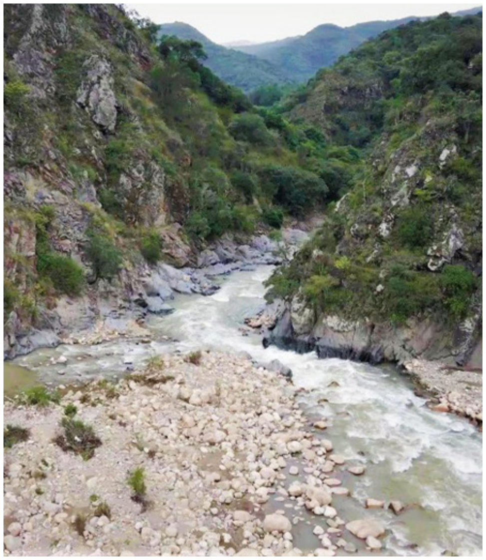

Figure 36

Azero River Basin. © PROCUENCA GIZ Bolivia, 2022 resilience to anticipate water variability and uncertainty from climate and non-climatic stressors in the Guadalquivir and Azero River Basins. The GIZ Climate Risk Assessment (CRA) builds the foundation for effective climate risk management (CRM). The aim of the CRA is threefold:

1. to identify risks
2. to assess the magnitude of the climate impact chains on people, assets, value chains, (critical) infrastructure, settlements, and ecosystems
3. to ascertain possible options for courses of action.

CRAs can support evidence-based and risk-informed decision making and planning in the context of climate change. This bottom-up approach allows stakeholders to comprehensively assess climate risk. Core components of GIZ's CRA methodology include:

- participation of stakeholders in the risk assessment process
- matching the information needs with a customized methodology that utilizes various and appropriate methods and tools
- assessment of climate risks triggered by the entire spectrum of hazards, from slow-onset processes to extreme weather events
- estimation of risk tolerance levels of the concerned system (e.g., vulnerable households)
- identification of a diverse mix of risk management measures from a range of tried and tested CCA and DRM measures including risk finance and insurance schemes
- consideration of non-economic losses and damages (i.e., moving beyond solely evaluating economic losses and damages)
- integration of results into a CRM framework that encompasses monitoring and evaluation and supports continuous learning.

The main purpose of the assessment was to help the members of river basin platforms and water user organizations to identify, integrate, and implement resilient water management innovations and practices for adaptation.

In close cooperation with the Technical and Social Committee of both river basin platforms and the coordination group of key stakeholders, the project supported the development of an online workshop series to: (a) elaborate and quantify climate impact chains, (b) identify the areas were higher climate risks were predicted, and (c) develop dialogues between local communities and policy makers to enhance the ability of technical specialists and policy makers to integrate considerations of site-specific climate risks into the river basin planning processes. A Robust Decision Making (RDM) approach based on an XLRM framework was used to develop a strategy against multiple future scenarios and critical climate uncertainties within the river basins. RDM approaches are meant to enhance the flexibility and likelihood of a successful outcome, and are designed in contrast to optimization-focused, probability-based decision making approaches (Bharwani, 2020). The XLRM framework incorporates elements of exogenous uncertainties (X), policy levers (L), relationships (R), and measures (M) (Lempert et al., 2003), allowing for the development of a strategy against multiple future scenarios and critical climate uncertainties within the river basins.

The most important lesson of the PROCUENCA project is that significant gaps remain at all levels — from local to regional to national — in understanding the risks of climate change and adaptation options available to manage risks in river basins. The second lesson is that there are no one-size-fits-all methods for climate risk and adaptation assessment; activities must be customized to the context across multiple sectors. Significant financial resources are required to help alleviate and adapt to the effects climate change has on the water sector. In this case, GIZ's CRA focused on supporting river basin stakeholders in mobilizing climate finance through the development of bankable proposals.

Sustained river basin resilience requires institutionalizing climate action along with capacity building and awareness-raising. Institutionalization requires the establishment of structures, processes, and capacities within transboundary, national, and river basin levels as well as raising awareness amongst the private sector and general public to call for a change in behavior — especially related to water use. To ensure resilience, all these elements need to support climate action planning, implementation, and monitoring.

Development initiatives are designed based on a set of assumptions about current and future conditions. Climate variability and change alter some of the information underlying those assumptions, requiring consequential adjustments to the approaches used to address development challenges. If decision making does not consider these shifting assumptions, then development outcomes will suffer.

It is evident that climate risks have the potential to threaten sustainable development achievements, such as poverty alleviation, global prosperity, or sustainable use of ecosystems and marine resources. Therefore, climate risks need to be addressed and considered in future planning at all levels, from individual river basins to national settings, and in all policy fields. CRAs are increasingly gaining importance among development cooperation stakeholders, and efforts to promote the mainstreaming of CRAs have been stepped up.

Together, these efforts must continue to foster awareness and motivate action on adaptation. In recent years, perceptions of climate change as a purely "environmental" issue have shifted — many now recognize it as a complex, cross-cutting risk that demands a broad-based, multifaceted response. Awareness is acute in the development sector, particularly, that climate change is a threat multiplier, with potential to erode gains or worsen conditions in areas with underlying socio-economic or institutional fragility. As GIZ continues to focus on building resilience through its journey to strategy, climate adaptation activities will be key to safeguarding these investments across the river basins (**Figure 37**).

Figure 37
Chiquitanía region of Bolivia. © PROCUENCA Paisajes Resilientes GIZ/UE Bolivia, 2022

Incorporating Climate Change into Colombia's Hydropower Planning

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Figure 38

Colombia's Sierra Nevada de Santa Marta mountains. © Ana Martinez, Unsplash, 2019

A bottom-up risk-based strategy can help decision makers design resilient water systems and hydroelectric infrastructure in the face of many climate scenarios. The CRIDA methodology provides technical guidance to satisfy such needs in this setting. A case study in Colombia concentrating on hydropower generation in the Magdalena River Basin offers a chance to test and further enhance the CRIDA technique while considering existing hydroclimatic data sources and their inherent uncertainties towards the future in a region facing drought risk and other climatic shifts.

The Magdalena River Basin is the most important in Colombia. It has a length of 1,612 km and a drainage area of 257,438 km^2, making it the primary fluvial branch in Colombia and the fifth-longest river in South America (**Figure 38**). Its headwaters are in the Andes at 3,300 meters above mean sea level, and it flows to the Caribbean Sea with an average discharge of 7200 m^3/s. The basin covers 24% of the country and generates 86% of the GDP, 75% of agricultural production, 95% of the thermoelectric energy, and 70% of the hydropower from its 26 hydropower plants.

The existing, new, and projected hydroelectric infrastructure rely upon studies conducted 40 years ago. Many still misrepresent the true hydropower potential due to outdated hydro-climatological data sources and unexplained uncertainties. Thus, the question is whether the old planning strategy is adequate to meet the increasing energy demands and changing climate in the Magdalena River system.

To address this question, a susceptibility assessment for hydropower generation in the Magdalena River Basin was conducted, with rainfall as a natural stressor. Rainfall was evaluated for climate variability through a bootstrapping process. Climate change was incorporated into the analysis representatively by reducing the bootstrapped rainfall by specific percentages. Based on the climate variability and climate change combinations, energy production levels were obtained through a Water Evaluation And Planning (WEAP) model for the basin. Results are presented comparing the energy output with the historic reference and denominated energy ratio, then observed in the stress tests. The goal of this assessment is not to follow a distribution function or to forecast future weather, but to show plausible climate combinations in the stress tests.

To stress the system as part of the climate change assessment, the rainfall was reduced by several percentages to represent a significant shift in the basin's weather. The first assessment looked to determine which driver had a more significant influence on the system regarding precipitation. On the Y-axis are presented the climate variability percentiles (the lower percentile is the drier scenario). On the X-axis are the climate change scenarios reducing the precipitation by percentages. Results for the accumulated deficit and average mean are shown in **Figure 39**.

The graph generated using the Accumulated Deficit Method in **Figure 39** exhibits steeper behavior when read vertically compared to the results from the Mean Average Method. That indicates that there is a broader range of energy ratio outputs for the same climate change reduction than for the first, where the results are vertical and thus the energy ratio constant. In this instance, the energy ratio nearly remains the same. So, regardless of the climate variability percentile, for a particular rainfall reduction percentage, the energy output retrieved is almost the same or close to it. When reading the test horizontally, it is evident that the energy ratio might vary significantly for different percentages of climate change mitigation. The results of the analysis indicate that climate change is the primary climate driver for the hydroelectric system under consideration.

This case study improves upon existing research in the basin by incorporating climate variability and change into the planning process, thereby allowing decision makers to make more informed choices for climate-resilient infrastructure.

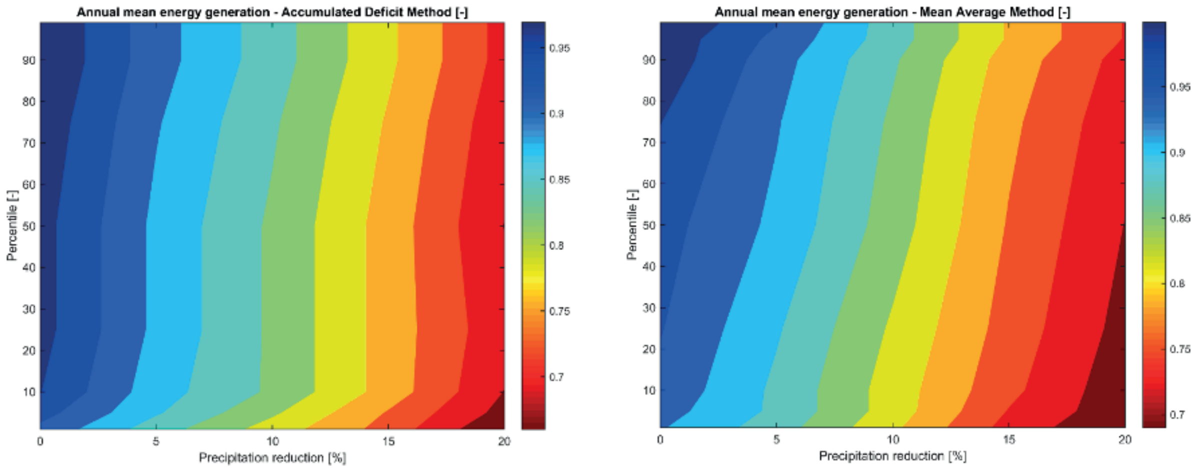

Figure 39

Stress tests as part of the climate change assessment. The left-hand graph represents average annual energy production compared to the reference scenario, calculated using the Accumulated Deficit Method. The graph on the right represents average annual energy production compared to the reference scenario, calculated using the Mean Average Method. © Gómez-Dueñas, 2022

Moving Forward: Recommendations for the HELP

The challenges facing countries as they work to build resilience towards disasters and climate change are daunting and require commensurate responses. The HELP will continue to play a leading role in guiding countries and communities towards appropriate actions aimed at addressing water and disasters. As climate change exacerbates existing water-related threats and adds layers of uncertainty with regard to future planning, bottom-up approaches for addressing climate risk should be incorporated into adaptation decision making processes.

The following set of recommendations are intended to provide the HELP with tangible, policy-oriented steps in creating “triple-win” actions that simultaneously promote disaster resilience, climate adaptation, and sustainable development.

- **Promote coordination across ministries and levels of government.** Comprehensive challenges require comprehensive solutions. The types of national programming that will be needed to address water-related disasters and other climatic threats cannot be limited to the remit of only one department within a government. Instead, they will require systemic solutions with support from offices that typically work independently. Coordination and information sharing among Ministries of Environment, Transportation, and Energy (for example) should be encouraged wherever possible.

- **Support integration and coherence of policies across global frameworks for DRR, CCA, and SDGs.** Improved coherence of action to adopt these three frameworks can save time and resources, increase efficacy, and further enable adaptation action. Climate resilience, water security, and sustainable development will be improved by coordinating development programs, policies, and strategies with adaptation efforts. Vulnerable communities can benefit from bottom-up, locally driven solutions contributing to numerous policy outcomes.

- **Include monitoring and evaluation systems in DRR and CCA programming.** Progress cannot be tracked if data are not collected and results are not analyzed. Specific metrics for documenting progress, measuring and communicating effectiveness (whether qualitatively or quantitatively), and reviewing gaps should be defined. Stakeholders should be involved in these processes from the beginning whenever possible to come up with shared metrics of success and for purposes of transparency. Further, combining cross-sectoral collaboration with technical and financial resources across planning and execution — including elements around capacity building, monitoring, and evaluation — allows governments to take adaptation action while simultaneously enhancing ambition.

- **At the project scale, use risk-based, bottom-up approaches to evaluate alternative interventions rather than projecting and optimizing for a future climate state.** Large-scale climatic projects include significant amounts of uncertainty. Rather than assuming one specific future and planning solely towards that, decision makers should focus on identifying and meeting desired levels of system performance through a stakeholder-centered, context-based approach consistent with the bottom-up methodologies presented in this report. These approaches are adaptive and cyclical in nature, taking into account new knowledge and information to better deal with uncertainties as they arise.

- **Recognize that disasters and water-related extreme events will undergo large shifts in intensity, frequency, spatial extent, duration, and timing — and plan accordingly.** Uncertainties around future climate conditions and extreme events mean that it is not sufficient to plan and prepare for disasters as currently experienced. Changes in weather extremes can occur simultaneously, leading to cascading, overlapping, and unforeseeable impacts. Droughts can become megadroughts and increase in intensity and frequency. DRR plans should incorporate elements of robustness to anticipated future stressors as well as flexibility and adaptability to scale up or pivot as conditions change.

- **Create or support capacity building programs within national climate and DRR plans to ensure that institutions understand climate risks and uncertainties and can better manage initiatives over the long term.** Initiatives addressing climate change and DRR will be implemented at all scales, from transboundary to local levels. To ensure long-term success of initiatives, individuals and institutions will need the support of training and capacity building activities. This applies to government institutions as well as numerous relevant external stakeholder groups such as resource management agencies and civil society organizations, among others.

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