REPORT

Managing Water for Economic Resilience:

De-risking Is Not Enough

WATER RESILIENCE FOR ECONOMIC RESILIENCE

WR4ER

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De-risking Is Not Enough

The **Water Resilience for Economic Resilience (WR4ER)** initiative works to inform the principles, theories, tools, and practices for ensuring that financial and economic institutions can manage and invest in building resilient economies that will endure and thrive amid a shifting climate.

WR4ER efforts are dedicated to defining the practice of water resilience for economic planning, evaluation, and management by aligning our existing activities and messages and developing new, common tools and approaches to enable water-centric economic resilience principles. More at **www.wr4er.org**.

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For Cees van de Guchte, who was one of the inspirations and creators of the WR4ER initiative. More importantly, he was a tremendous colleague and friend.

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Preface

Awareness is slowly increasing on water's pivotal role in the risks the world faces today and for the years to come. This is especially true for the effects climate change has on the water cycle and the resulting impacts on our economies. With this recognition, it has also become increasingly clear that proactive measures are needed to address these issues. This document aims to shed light on the importance of integrating water resilience into economic planning, offering guidance and practical examples to policy-makers, financial institutions, and other stakeholders.

Through a series of case studies, we explore the operationalization of water resilience in different contexts. These case studies showcase the practical applications of water-centric economic resilience principles, demonstrating how they can be implemented to build resilient economies. From Australia's Murray-Darling Basin to Chile and the Inner Niger Delta in the Sahel, each case study delves into the challenges faced by these regions and the strategies employed to improve water resilience.

For example, the Australian case study examines the use of cap-and-trade mechanisms and cost-reflective pricing in the Murray-Darling Basin, highlighting their contribution to improved water resilience and economic stability. Another case study focuses on Chile's experience with privatizing water and sanitation services, emphasizing the benefits brought about by private sector involvement.

Throughout these cases, we emphasize the importance of leveraging climate finance mechanisms to support water resilience projects. We also underscore the need for financial institutions to incorporate resilience components in their investment strategies and incentivize the adoption of resilient practices. Additionally, we highlight the significance of capacity building and training in driving institutional changes and fostering a reorientation towards resilience.

This document serves as a valuable resource for macroeconomists, economic planners, central bankers, finance and development ministries, and other stakeholders involved in water management and economic resilience. It provides insights, recommendations, and practical examples that can inform policy development and investment decisions, ensuring the long-term sustainability and resilience of economies in the face of climate change.

We hope that this document inspires and empowers you to take proactive steps towards integrating water resilience into economic planning and decision making. By considering water as a medium for resilience and implementing sustainable water management strategies, risk reduction procedures, and resilient governance frameworks, we can build resilient economies that thrive in a changing climate.

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Executive Summary

The following report and case studies discuss the importance of climate change in macroeconomic decision-making and the need for new approaches to planning and investment. It highlights the gap between climate science, economic planning, and investment decisions, and the limitations of traditional economic analysis tools in incorporating climate change. The concept of resilience is introduced as essential for economic planning and the need for proactive measures to address various environmental impacts. Water is identified as a key element for resilience and economic development, with a focus on the importance of integrating water resilience into economic planning. The text concludes by emphasizing the need to incorporate resilience in economic and quantitative terms and the potential for resilience to emerge as a new economic sector.

Key insights from this report fall within three clusters:

1. **Prioritize resilience in economic planning by leveraging water's potential as a medium for resilience**

- Resilience involves the capacity to reconfigure systems, redefine objectives, and reform institutions. Facilitating strategic adjustments in the face of significant uncertainty is essential to achieve long-term economic efficiency.
- Resilience to deeply uncertain future events must become an economic objective, which includes managing the uncertainties and risks that extend beyond irreversible climate transformation and integrating them into macroeconomic planning.
- Economies will continue to experience increasing water-related climate variability such as droughts and floods — often with the same localities experiencing wider swings rather than just in one direction. These trends are often not well captured by climate models, but regional data suggests these extremes will increasingly be out of historic norms. Increasing variability should be considered in current economic models.
- Treating water resources as a fixed, stable, and reliable input in investment and planning can lodge systemic economic and financial risks. Economic feasibility assessments and planning need to consider the present value of future water costs as benefits in accordance with climate change scenarios.
- Water serves as a shared economic link between projects and sectors as well as across political, administrative, social, and ecological boundaries. Therefore, managing water as a dynamic linkage can catalyze structural transformation and resilience across projects, sectors, and boundaries.

2. **Manage economic growth's hidden water commitments that increase consumption**

- Economic models often exhibit a positive correlation between growth and water consumption, yet growth is also sensitive to water-related shocks and stresses, especially associated with water scarcity and competition. Many of these linkages may be hidden, such as water embedded within food production and processing systems, energy production, or data management. Decoupling economic growth from water consumption and/or investing in growth that includes independent and redundant water supply systems can reduce forced tradeoffs, conflicts, and social and economic crises.

- Assessing water's real value and pricing in the economy is often underestimated and overlooked. Exacerbating this issue is water's role as a basic and widely subsidized common good. Valuing water's shared value should consider its importance of water for the whole economy.

3. **Assess water resilience as a prerequisite for financial feasibility**

- De-risking strategies have a role for including climate adaptation measures to buffer minor disruptions and stresses but may not capture or address major climatic and environmental shifts, which are better managed through resilience.
- Financial instruments are designed to evaluate the value of benefits associated with an investment or project, often with a hidden assumption of minimizing seemingly unlikely or uncertain trends or disruptions. Thus, conventional analytical methods often devalue and dissuade climate adaptation components. This oversight can lead to underinvestment in initiatives and capacities that are crucial for long-term adaptive capacity to changing conditions.
- Traditional financial concepts such as net present value and discount rates should give greater weight to future costs and benefits and reflect a broad range of potential futures. Economic instruments should also be incorporated among resilience measures to help accommodate for dynamic water cycle fluctuations.
- Leveraging fiscal, monetary, trading, and regulatory policies with aligned incentive schemes can expedite the adoption of water-resilient investments.

PART 1

Introduction

For decision-makers guiding macroeconomic decisions, climate change represents much more than what former US Secretary of State Rex Tillerson called an "engineering problem." Climate change is upending trade relationships, stranding well-established economic sectors and key investments, altering socioeconomic equity, and — in some cases — creating new but often unrecognized opportunities. Current approaches to macroeconomic planning are implicitly either discounting climate trends or assuming that taking a simplistic "de-risking" approach will be enough. Climate change is clearly a macroeconomic issue, but one that requires new lenses.

Major scientific and advocacy organizations regularly publicize maps that show alarming "hot spots" — regions and countries highlighted to show where dire climate impacts are occurring. Despite these warnings, the gap between climate science, economic planning, and investment decisions has remained largely unbridged. Almost twenty years ago, the influential Stern Review warned of substantial economic damage from climate shocks and stresses without rapid decarbonization in order to minimize the need for adaptation (Stern, 2006). The best available science now suggests that even if all human-sourced carbon emissions ceased, we would still be committed to decades or centuries of additional "zombie" anthropogenic climate change given the unfolding of atmospheric carbon continues (IPCC, 2021). If the question posed in 2006 was how to avoid the need for adaptation, our challenge now is how to ensure that our adaptation and resilience efforts are strategic, effective, and ambitious.

Resilience as an Essential Economic Concept

For years, sustainable development policies have been guided and shaped by economic science to generate wealth and prosperity and alleviate poverty. A decade after the Stern Review, William Nordhaus won a Nobel Prize for integrating climate change into long-term macroeconomic analyses. He argued that climate change produces cascading economic effects, affecting work capacity and productivity. Among the most serious consequences for the world economies he anticipated were the decrease in crop productivity, price rise of basic foods, increased human mobility pressures, and overall resource scarcity, including water. Yet, economic planners have commonly overlooked the complexities and underestimated the importance of water resilience for the economy. A key insight from Nordhaus was that macroeconomic models used to evaluate and predict key macroeconomic variables like GDP, prices, or employment still do not incorporate natural resource variability or other qualities, such as for water resources. The gap in economic measurement to integrate a more natural resource attuned approach to national accounting has been recognized since at least 1994 (National Academies of Sciences, 1994) yet largely remains an afterthought.

Traditional economic analysis tools such as Net Present Value (NPV), Economic Internal Rate of Return (EIRR), and cost-benefit analysis are instrumental in evaluating programs and investments. They provide frameworks for assessing the economic and financial viability of investments by comparing alternatives and optimizing tradeoffs between competing uses for scarce resources. Nevertheless, they function under the implicit assumption of constant climate conditions. However, climate change violates this premise, thereby introducing a level of uncertainty and disruptions that these tools fail to incorporate. The most common response to this challenge has been two-fold: 1) assuming that uncertainty can be reduced to comparable indicators such as expected returns, the frequency of extreme events as expressed through "return periods," average and dispersion measures, and other variables by using past observations and data to understand future risks, or 2) discounting uncertain and/or distant climate impacts, such as shifts in the frequency or intensity of extreme weather events or shifts in the timing and form of precipitation. Nevertheless, the irreducible uncertainty has been an integral part of all future scenarios that recognize the impacts of climate change. These two approaches are difficult to reconcile with climate science and resilience.

Nowadays, and in response to those uncertainties, new economic thinking is emerging to create more robust economic and financial models that enable policy-makers to identify and select the "best economic" adaptation investment. These models extend beyond cost-benefit frameworks analysis to include multi-metric evaluations by factoring in risks, uncertainties, social inequalities, and behavioral factors. They also stretch their boundaries to recognize and quantify a wide spectrum of the direct and indirect benefits and costs related to adaptation. Their objective is to enable policy-makers to incorporate forward-looking outlooks to design strategies with adaptable pathways, diversification alternatives, and nature-based solutions to prepare for different scenarios.

De-risking has also emerged to ensure that an investment, policy, or sector will continue to operate under reasonable performance levels in a given set of conditions. It incorporates "reducing, transferring, or mitigating the risks associated with low-carbon and climate-resilient investments" (Choi & Laxton, 2023). Usually, de-risking results in modest but sometimes also significant changes to an investment to maintain feasibility, normally by focusing on a handful of direct and often coarsely defined climate impacts. These changes may also be insufficient to establish resilient frameworks for societies and economies to prosper over time given the progressive pace of climate change. De-risking does not capture system level changes, such as climate transformation.

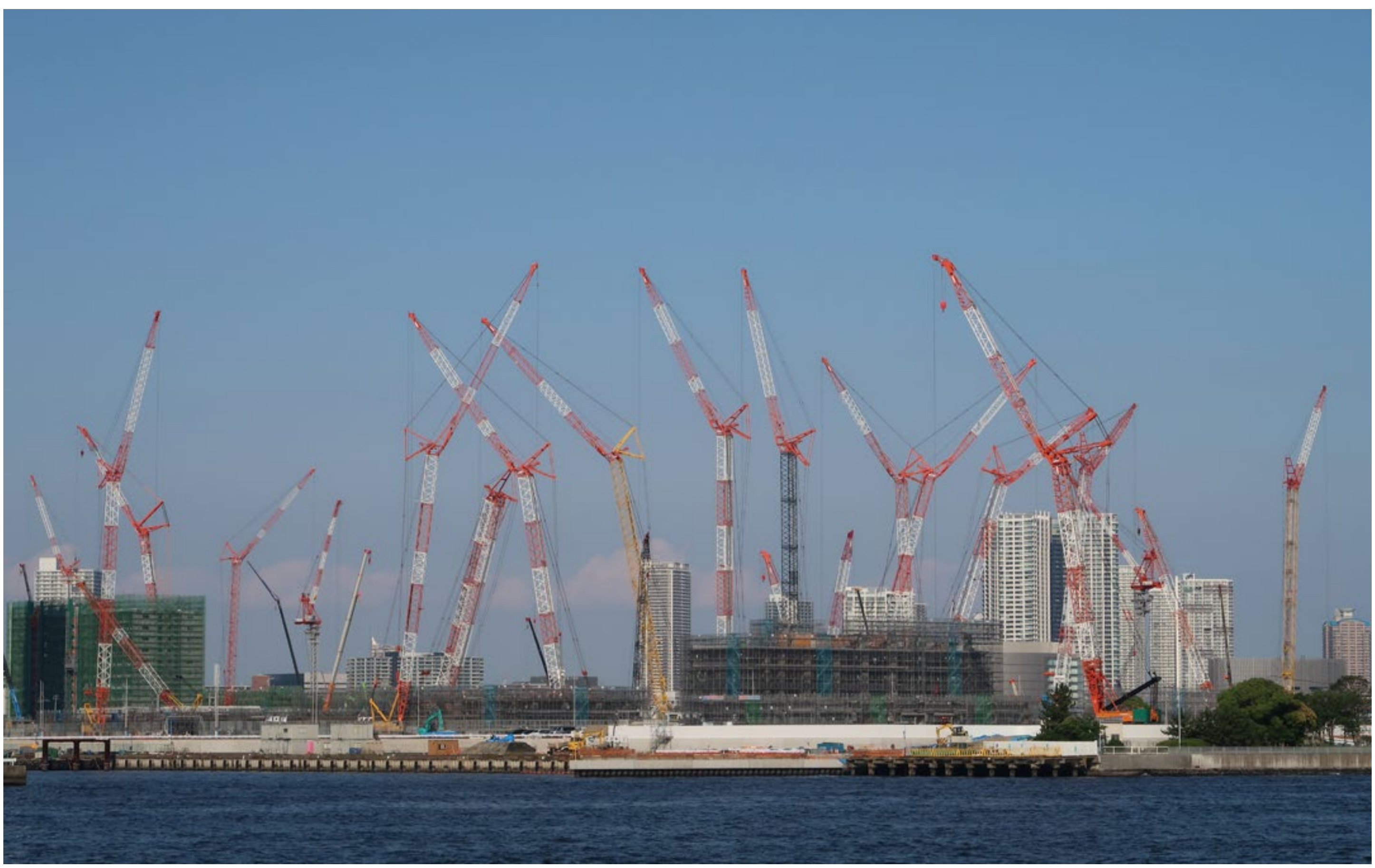
Ignoring climate change impacts in economic planning or assuming that alternative, unplanned-for solutions will emerge seems risky and unrealistic. Effective adaptation and resilience are the outcomes of planned and coordinated efforts rather than believing that spontaneous adaptation responses will match the scale and scope of challenges just in time (WRI, 2019).

The development of climate resilience across a wide range of disciplines suggests that highly optimized solutions may also be "brittle" when confronted with unforeseen events. Major projects and sectors may be prone to drops in efficiency, social and sectoral conflict, forced tradeoffs, de-investment and capital flight, or even systemic failure if key assumptions are not tested for their sensitivity in advance.

In practice, economic resilience may appear to reduce economic efficiency in the short term as we incorporate both high confidence impacts as well as less certain, long-term, and indirect impacts. Incorporating resilience measures such as redundancy, backup inputs, stockpiles of key resources, and alternate supply chain systems may truly be efficient if we consider the challenges of a broader range of environmental and social conditions. However, over the medium to long term, economic efficiency will grow as risks fall and progress and sustainability are enhanced in a larger array of circumstances. In other words, resilience bears an upfront cost, but with considerable long-lasting benefits. Policy-makers and financial institutions can enhance economic resilience by ensuring that critical sectors such as energy and healthcare infrastructure systems can operate across a wide span of climate conditions over their operational lifetimes. Strategies that embrace this uncertainty — like adaptable pathways, diversification, nature-based solutions, and flexible water allocation — are essential for preparing for dynamic and uncertain future scenarios. Furthermore, Economic Instruments (EIs) in the context of adaptation can enable more efficient use of scarce resources and help in creating an effective risk sharing model among agents in society. EIs can include "taxes, subsidies, risk sharing, and risk transfer (including insurance), water pricing, intellectual property rights, or other tools that send a market signal that shapes behavior" (Dubeux et al., 2014).

Defining Resilience in Practice

Resilience and climate adaptation represent distinct but interconnected concepts (Mehryar, 2022). Climate adaptation is often defined as the comprehensive strategy that ensures sectors, projects, or assets remain prepared and responsive despite climate-related challenges. The Intergovernmental Panel on Climate Change (IPCC) has articulated it "as the process of adjustment to actual



or expected climate and its effects," going on to specify, "In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities…In natural systems, human intervention may facilitate adjustment to expected climate and its effects" (IPCC, 2022a).

Resilience is more ambitious and recent as a concept and approach. Resilience emerges as a byproduct of climate adaptation for social, economic, and ecological systems. Rather than delineating a specific set of impacts and responses, resilience assumes that new and often unpredicted disturbances will occur, often with indirect and unforeseen effects. According to the IPCC, "resilience…is the capacity of social, economic, and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure…while also maintaining the capacity for adaptation, learning, and transformation" (IPCC, 2022a). The elements of reorganizing and developing a capacity for transformation strongly distinguish resilience from "sustainability." As recognized in a World Bank report led by economist Stephane Hallegatte, resilience must focus on the "deep uncertainty" presented by the interaction of climate shifts with many other nonlinear and difficult to predict trends (Hallegatte et al., 2012). Traditional measures of policy effectiveness, such as efficiency and robustness, may be counterproductive when we need to value flexibility, the ability to adjust targets and systems, and redundancy within and between sectors as new conditions emerge. Can we see new rules before we pay the consequences for breaking those rules?

Thus, resilience entails taking proactive measures to introduce new societal structures, including economic, regulatory, and institutional frameworks, corporate practices, and cultural norms, to not only withstand but also anticipate and address the various environmental impacts (GFDRR, 2013). Given the rapid pace and scope of climate change — quickening sea-level rise, extreme fire events, tropical cyclone activity, permanent loss of snowpack and glaciers, shifts in the water cycle and ocean currents — resulting in changes that fundamentally and in most cases irreversibly alter our landscapes, resilience is essential. Resilience empowers current systems to evolve and transform. It questions the current conditions and advocates for systemic alterations where incremental adaptation measures are insufficient (Mehryar, 2022; Shammin, Haque, & Faisal, 2022).

Water as a Medium for Resilience

Resilience is not an accident — it must be planned for and invested in. The concept of resilience is gaining traction across numerous international and multilateral organizations and has been incorporated in the United Nations Sustainable Development Goals (SDGs) and the 2015 UNFCCC Paris Agreement. The most recent notable voice in this area is the IPCC, which has recently called for the widespread implementation of "water-based adaptation" in order to ensure that resilience captures the connective, cross-sectoral, and integrative qualities of water resilience (IPCC, 2022b). This recognition is paralleled by significant paradigm shifts in technical disciplines such as engineering and hydrology that are integrating resilience measures into their core practices. In the meantime and despite these efforts, the notion of resilience has not been fully embraced as an economic principle. Are there strategic interventions we can use to maximize coherence and efficacy in macroeconomic planning? Water has been proposed as both a systemic hazard that reduces resilience and as a systemic solution for planning and implementation.

Water was quickly recognized as the central socioeconomic climate hazard by Sadoff and Muller (2009). Water is frequently identified as the primary extreme climate events, as evidenced by nearly 74 percent of natural disasters between 2001 and 2018 affecting over three billion individuals being classified as water-related (UNICEF, 2022). But while climate change has been called a “risk multiplier” by the intelligence community, water has been identified as a “resilience multiplier” through its ability to link infrastructure, institutions, and sectors as a shared dynamic resource (Matthews, Timboe, & Harpham, 2022). Water holds a strategic position at the nexus of environmental, social, and economic spheres, which accentuates the capacity of water resources to introduce systemic and structural changes and catalyze structural transformation and resilience (Smith & Matthews, 2019; Timboe, Pharr, & Matthews, 2020).

Why Water Is Important to Economic Resilience

Water, especially freshwater resources, holds a key role in economic development and has become a central focus for climate adaptation and resilience. Clean, abundant freshwater is crucial for core economic development issues such as trade, urbanization, transport, energy production, food security, and public health. A dynamic, uncertain water cycle undermines macroeconomic assumptions of modest changes in these areas.

Evidence-based literature indicates that the current worldwide economic system is significantly disturbing the water cycle through emissions of greenhouse gasses, the devastation of natural habitats, and contamination of natural resources. This contributes to the escalating scarcity of water and the projected increase in droughts. These environmental disruptions have significant costs that are not only omitted from the current economic models, but also affect the governance and stewardship of water resources that can in turn lead to market failure. This necessitates the inclusion of such variables in strategic economic planning where water is managed as an economic good. Policies must focus on finding the most beneficial and efficient use of water, given its limited supply. This involves making decisions about allocating water where it can generate the highest net benefits, whether those are measured in terms of economic returns, social welfare, or environmental sustainability (Atapattu, 2002).

As early as 2009, the scientific community pointed out how long-standing assumptions that the past could predict future water conditions were no longer true — let alone useful — for technical planning, design, and operations for facilities and projects that considered any aspect of the water cycle, particularly water sector infrastructure. Teams spanning institutions such as the Rand Corporation, Deltares, OECD, the US Army Corps of Engineers, UNESCO, the World Bank, and the Asian Development Bank have subsequently established structured decision-making procedures to compensate for at least some of these water uncertainties in project-level feasibility and de-risking studies. Collectively, they point to several core aspects of analytical climate resilience:

- Risk assessment should consider both high- and low-confidence climate impacts.
- System-level analyses are important for understanding both direct and indirect interactions. Feasibility and modeling studies that focus on narrowly defined spatial scales and temporal scales may miss significant drivers.
- Robustness to an array of plausible futures and decisive interventions to high-confidence impacts remain an essential component of resilience.
- Planned flexibility and adaptability, and long-term temporally staged structured decision-making to accommodate the uncertainties associated with long-lived infrastructure, resource management, and governance and regulations are essential to address a broader array of credible, diverse futures. Flexibility is a newer, less familiar component of resilience.
- Stress testing and modeling water-related climatic as well as non-climatic impacts and shared and cross-sectoral water relationships are essential to cope with ongoing climate stresses and long-term transformation.

Most of our current tools for evaluating and approving investments discount or ignore these aspects of resilience in economic and quantitative terms. In fact, many disciplines are actively responding to these insights, which is itself leading to quite innovative approaches to go beyond seeing risk and to enable decision-makers to directly invest in resilience. Over time we may be seeing resilience itself arise as a new economic sector as these concepts develop.

Who Needs Economic Resilience?

The Water Resilience for Economic Resilience (WR4ER) initiative is designed to advocate for water resilience as an economic concept for macroeconomists, economic planners, central bankers, and finance and development ministries — as well as the groups that interact with these audiences, such as insurance and reinsurance programs and companies, commercial banks, credit rating agencies, city planners, corporations that operate or depend on critical infrastructure, and funders and designers of critical infrastructure programs, including development and commercial banks. In most countries, these groups have identified climate change as a driver primarily relevant to transitions in energy production and decarbonization.

Conceptually, economic resilience at these levels includes diversification, coherence in water use across sectors, and robustness and flexibility built into critical parts of the national economy. However, we also believe that there are more detailed, quantitative, and structured socio-economic interventions to foster water resilience as a driver for economic resilience that should be considered, which are detailed in Part 3.

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PART 2

Case Studies: Operationalizing Water for Resilient Economies

Although water resilience is a new concept, much evidence already exists for specific interventions, insights, and approaches for operationalizing water resilience. Part 2 explores this evidence through a series of case studies, underscoring the critical role of water resilience in both national and regional economies. The following cases demonstrate that water is a powerful medium for resilience, an operational approach, and that many practical examples already exist for policy-makers.

Angola: Moving from an Oil-Based Economy to Water-Centric Resilience

Excerpted from:
World Bank Group. 2022. *Angola: Country climate and development report*. CCDR Series. Washington, D.C.: World Bank Group.

Key Messages

- Water resources are the pillar of climate resilience for Angola. Climate-related hazards such as flooding, coastal erosion, and droughts are hindering Angola's economic development, and the situation is expected to worsen with climate change. Southern Angola has experienced a severe and prolonged drought over the last decade, leading to high levels of food insecurity and water scarcity for millions of people.
- In Angola, agriculture and energy are critical sectors that require urgent attention to build climate resilience and ensure inclusive development. Angola heavily relies on hydropower, making it particularly vulnerable to climate change impacts, and over half of the population lacks access to electricity.
- Total economic losses due to drought in agriculture may rise from as much as US$ 100 million per year nationwide today, to more than US$ 700 million per year by 2100. The productivity of fisheries is also projected to decline, with the maximum catch potential expected to decrease by 43.7 percent by 2050 and 64 percent by 2100.
- The Ministry of Finance and the Ministry of the Economy and Planning should collaborate

to create a fully costed plan for resilience investment. This will require coordination across the government and the allocation of limited resources to ensure that all sectors achieve resilience. Before committing to large investments, sector ministries will need to understand the tradeoffs between investment choices and develop a portfolio of climate resilience projects with identified public and private financing sources.

- Angola is reforming its water sector, creating the independent Regulatory Institute for Energy and Water Services (IRSEA) and the National Water Resources Institute (INRH). The country also lacks basin councils and needs to implement and improve water resources management frameworks to prepare for droughts and floods. Institutional capacity remains weak and needs to be improved at key administrative levels.
- Building the resilience of Angola's water sector requires a multifaceted approach: 1) strengthening the WRM framework and investments in water storage, 2) ensuring the sustainable operation and maintenance of infrastructure, 3) strengthening provincial water and sanitation utilities, and 4) investments to expand water and sanitation access to these plans.

Introduction

Climate change is already affecting people's lives and livelihoods in Angola, as well as the Angolan economy. The country is experiencing increasingly severe and frequent climate hazards — including the South's worst prolonged droughts in decades. Climate change impacts also come with a heavy price tag: climate-related disasters (e.g., floods, storms, droughts) cost Angola nearly US$ 1.2 billion between 2005–2017, and on average droughts alone affect about a million Angolans every year. Impacts of climate variability on Angola's water resources are expected to be particularly severe and will affect food and energy production, as well as hydropower, on which Angola relies for most of its electricity.

Angola has significant renewable capital, including agricultural land, forests, water resources, and, above all, its people, who can facilitate this process. But climate change also threatens these renewable assets, and necessary investments in

Angola's Nationally Determined Contribution

Angola is a party to the Paris Agreement and in 2021 submitted an updated Nationally Determined Contribution (NDC). Also in 2021, Angola submitted a detailed Second National Communication under the United Nations Framework Convention on Climate Change (UNFCCC). Angola's greenhouse gas (GHG) emissions account for less than 0.21 percent of the total global GHG emissions. According to the country's updated NDC, its total GHG emissions in 2015 were 99.99 million metric tonnes (Mt) CO_2e or 3.74 tonnes per capita (Republic of Angola, 2021), which is lower than the global average of 6.39 tonnes per capita for that year (Climate Watch, 2019). Based on global GHG emissions of 46.87 billion tonnes (Gt) CO_2e in 2015, Angola's emissions would constitute about 0.21 percent of the total global emissions according to their own estimates.

climate resilience will be critical to realize their potential.

To inform the source report for this case study, a robust climate science impact analysis was undertaken, followed by in-depth analysis of macroeconomic and sectoral implications of climate impacts on Angola's future development prospects. The report was developed over the course of a year, leveraging technical teams from across the World Bank, the International Finance Corporation, and the Multilateral Investment Guarantee Agency, working in close partnership with the Government of Angola through its Ministry of Economic Planning and other key climate-sensitive sectoral ministries.

Current Economic Context

Angola's oil-based economic growth of the past two decades has not delivered inclusive development and is now losing steam. After the end of a 27-year civil war in 2002, Angola enjoyed several years of robust, if uneven, economic growth, led by oil exports. In 2021, national accounts show the oil sector still contributed 27 percent of gross domestic product (GDP) in 2021. In the meantime, around 50 percent of the Angolan labor force are employed in agriculture, predominantly as subsistence farmers. Despite agriculture only contributing approximately 9 percent to the country's GDP and utilizing just one-third of its five million hectares of arable land, it remains the occupation for 51 percent of the country's labor force.

Angola's development priority is therefore to use the revenues from its dwindling oil wealth to diversify its economy, reducing its dependency on the petroleum industry and creating opportunities for sustainable growth and job creation. As of 2020, it was the eighth-largest economy in Sub-Saharan Africa, but still categorized as a lower-middle-income country, with gross national income (GNI) per capita of US$ 2,140. Recognizing this challenge, Angola's President has stated that diversification is "a matter of life or death" for the country, and the next National Development Plan (2023–2027) features economic diversification as one of three focus areas (along with human capital and infrastructure).

Angola's 2018 Systematic Country Diagnostic identifies agribusiness, fisheries, and manufacturing as potential (non-extractive) industries where Angola's economy could diversify and create more employment opportunities. The potential of these sectors is also acknowledged as part of the most recent Country Private Sector Diagnostic by the International Finance Corporation (IFC).

Climate Change in Angola: Impact on Economic Development

Angola's economic development is being hindered by climate-related hazards such as flooding, coastal erosion, and droughts, which are expected to become more intense with climate change. Southern Angola has experienced a severe and prolonged drought over the last decade. This has resulted in high levels of food insecurity where an estimated 3.81 million people in the six southern provinces have reported insufficient food in addition to water scarcity for over 1.2 million people. The previous severe drought in 2015–2016 led to 80 percent of existing boreholes becoming nonfunctional due to water scarcity and disrepair.

Climate change is not just a future threat, but already a reality in Angola. Total economic losses due to drought in agriculture may rise from as much as US$ 100 million per year nationwide today, to more than US$ 700 million per year by 2100. The productivity of fisheries is also projected to decline, with the maximum catch potential expected to decrease by 43.7 percent by 2050 and 64.0 percent by 2100.

With southern and southeastern Angola projected to become drier, hydropower production on the Kunene River, for example, is expected to decline. Meanwhile, in urban areas — where two-thirds of Angolans already live, and a majority of jobs are — climate change is likely to exacerbate water scarcity, bring more intense storms and coastal flooding, and increase the risks associated with inadequate sanitation. Sea-level rise is expected to have a significant impact on coastal settlements in Angola, where more than 50 percent of the population lives, affecting housing, roads, and industrial and commercial infrastructure.

Heat waves are another threat Angola faces. A recent study of over 150 large African cities predicts that heat waves, exacerbated by the urban heat island effect, will expose 20–52 times more people to dangerous heat conditions by the end of the century. Luanda is among the five most exposed cities, with the highest increase in relative terms compared to the historical period. The city has less than 1 m2 of green space per capita, much lower than comparable cities and the recommended 9 m2 by the World Health Organization. The urban heat island effect is expected to increase energy costs related to air conditioning, air pollution levels, and heat-related illness, and mortality and is projected to worsen due to climate change.

Moving Towards Resilience: Defining a Strategy

Five pathways have been identified to achieve a vision of a future Angolan economy that is both diversified and climate-resilient, with opportunities for all. Tailored to the national context, these approaches were identified in dialogues with the Government of Angola and build on national development priorities. Angola is rich in natural capital — not only oil, gas, and diamonds, but also abundant water resources, renewable energy potential, and fertile arable land. Therefore, to shift away from an economy driven by oil and gas extraction and toward a sustainable and diversified economy based on renewable natural capital, this Climate Change Development Report (CCDR) recommends investing in and building the resilience of key sectors, notably: 1) water resources, 2) agriculture and fisheries, and 3) renewable energy. Delivering the vision of a climate-resilient and diversified economy also entails 4) enabling green and resilient cities with economic opportunities for all Angolans, and leveraging Angola's young population by 5) boosting human capital, through expanded, climate-resilient access to basic services and fostering a culture of climate preparedness.

Water resources are the pillar of climate resilience for Angola. Angola is endowed with plentiful water resources that, if well-managed in the context of climate change, can produce clean electricity, abundant food, and livable cities. Angola's vast water resources are unevenly distributed. Seasonal and interannual rainfall variability is high and floods and droughts have been part of a natural cycle that is expected to intensify with climate change, leading to a decrease in overall water availability.

To achieve water resilience, the source report recommends: 1) strengthening basin water management offices and councils to balance competing demands with limited and variable water resources, 2) investing in water storage, including groundwater and watershed storage (i.e., nature based solutions) to mitigate flood risks and store water for dry periods, 3) expanding access to clean water and sanitation across rural and peri-urban areas (US$ 2 billion), and 4) rehabilitating and strengthening the operation and maintenance of dams and rural infrastructure to serve productive uses (US$ 1 billion).

In Angola, agriculture and energy are critical sectors that require urgent attention to build climate resilience and ensure inclusive development. Angola heavily relies on hydropower, making it particularly vulnerable to climate change impacts, and over half of the population lacks access to electricity. Expanding electrification and building resilience in the power sector are, therefore, essential to realizing Angola's development vision.

Agriculture in Angola is crucial to food security and holds tremendous commercial potential, but climate change will require significant reforms to realize the sector's potential as an engine of growth. Only about a third of the arable land is cultivated, and only about 2 percent of arable land benefits from machinery or even animal traction. Irrigation is also rare, and unsustainable practices are common, resulting in forest loss, reduced biodiversity, and other environmental burdens. Angola also has large potential for fisheries and aquaculture, but it needs to carefully manage its resources to protect ecosystems and promote sustainable growth. Overfishing and changes in hydroclimatic conditions have greatly affected the sector.

Without effective adaptation, climate change is likely to have a major negative impact on agriculture — and thus food security. To build the resilience of food systems to rising climate shocks in Angola, the CCDR recommends scaling up climate-smart agriculture practices and climate-smart fisheries technologies, rehabilitating old irrigation perimeters and infrastructure left in neglect following the civil war, and building flexible, decentralized systems for farmer-led irrigation development, while also expanding extension services support and repurposing agricultural subsidies to benefit all farmers.

Cities can be catalysts for growth and job creation, but they need to be resilient, livable, and inclusive to realize this potential. Two-thirds of Angolans live in urban areas, and by 2050, the share is expected to rise to 80 percent, with cities hosting three times as many residents as they do today. To promote clean, compact, and connected urban development in Luanda and secondary cities, the CCDR recommends investments in comprehensive solid waste management systems to curb methane emissions, reduce flooding, and improve quality of life. Local governments will need to coordinate and lead implementation of urban resilience measures — such as risk analyses, integration of risk maps into territorial plans, and inspection and enforcement of zoning regulations. Flood early warning systems, especially for coastal zones, and nature-based solutions for flood and landslide protection, will also be critical measures to live with rising climate risks.

Finally, social and cultural capital are critical for Angola's future. Angola's most important wealth is its people, who are young (the median age is 17) and can power climate-resilient development across sectors — but only if they are healthy, well-nourished, and properly trained. The creation of a culture of climate preparedness, especially through education reforms, will contribute to enhancing national capacities for climate resilience. In order to raise a climate-conscious generation, it is critical to start in the early years and instill values of shared responsibility and environmental stewardship in primary education. As Angola prepares a new strategy for its tertiary education sector, prioritizing programs that prepare workers for careers in adaptation and low-carbon technologies (i.e., "green jobs") is an opportunity to boost its future competitiveness.

Water Resilience Priorities

A key priority for Angola today is to put climate resilience at the center of all planning, integrating climate risks and adaptation measures into all sectoral plans and strategies, the medium-term fiscal strategy, and territorial planning instruments. Sectoral, national, and subnational planners need to ask, "What new climate risks/opportunities do we need to adapt to, and what can we adapt towards?" The next National Development Plan can propose an integrated package of climate resilience investments, policy reforms, and institutional changes.

The Ministries of Economic and Planning and Finance play a key role and can lead an inter-ministerial coordination structure with specific responsibilities and timelines for line ministries engaged in implementing climate action. Planning is especially critical in the climate-sensitive water sector to address competing demands amid growing variability. Finally, public investment management needs to be strengthened and made more climate-responsive, employing mandatory assessment of new investment projects in line with national climate priorities.

Key government institutions should be empowered to tackle the climate crisis and ensure adequate financial and human resources. Professional and well-trained staff and adequate resources are both critical. Across all sectors analyzed in this CCDR, existing capacities will need to be enhanced to tackle the new exigencies of climate risk management. Data are also essential. As such, it will be critical to bolster the National Hydrometeorological Agency (INAMET), mandated to monitor and predict climate risks, as well as related agencies involved in early warning/early action systems.

A culture of proactive risk management and climate preparedness should be promoted. Such a shift is crucial in a world where multiple sequential and often overlapping crises are the "new normal." As basic services improve, they need to incorporate disaster preparedness plans. Mainstreaming climate-related disaster risk management, including through better early warning systems, will reduce the costs and shorten the response time when disasters hit. Finally, Angola needs to have the financing in place to deal with climate-related disasters quickly when these hit, while avoiding a large diversion of expenditures from its development priorities through financial planning and pre-arranged disaster contingency resources.

A fully costed resilience investment plan should be jointly developed through collaboration between the Ministry of Finance and the Ministry of the Economy and Planning. Because achieving climate resilience is a cross-cutting issue requiring coordination across the government, these two ministries play central roles in strategically allocating limited resources and planning investments to meet Angola's climate-resilient development goals and diversify the economy. Before committing to large investments, sector ministries will need to fully understand the tradeoffs between investment choices and develop a comprehensive portfolio of climate resilience projects that will achieve the resilience of every sector, with clear public and private financing sources identified to fund them.

Making Water Real: Implementing Water Resilience Investment, Governance, and Practice

Sustainable water management is crucial to human well-being and a vital economic resource for agriculture, energy production, industry, urban development, and the environment — thus Angola's economic diversification and climate resilience. While Angola is rich with water resources, these are unevenly distributed, with a rainfall gradient decreasing from north to south and influenced by topography, with most rain falling on the plateau and very little across the southern lowlands and coastal fringe. In addition, seasonal and interannual rainfall variability is high, and floods and droughts have been a natural cycle, expected to intensify with climate change and leading to a decrease in overall water availability. If Angola is to develop its productive sectors, it will need to make significant investments to strengthen its water resources governance and manage increasing demands on limited and variable resources.

Angola's water sector is undergoing a process of reform. The independent Regulatory Institute for Energy and Water Services (IRSEA) has been created, and a water resources mandate has been set up through the National Water Resources Institute (INRH). The provincial water utilities, IRSEA, and INRH are still maturing and face capacity challenges. Only two basin administration agencies exist, and no basin councils have been created. Water resources management (WRM) frameworks need to be implemented and strengthened to set the foundation for drought and flood preparedness plans. Yet, institutional capacity remains too weak to operationalize them at key administrative levels.

Building the resilience of Angola's water sector requires a multifaceted approach: 1) strengthening the WRM framework and investments in water storage, 2) ensuring the sustainable operation and maintenance of infrastructure, 3) strengthening provincial water and sanitation utilities, and 4) investments to expand water and sanitation access. In order to address Angola's most pressing water needs and ensure the resilience of the sector, this CCDR offers the following recommendations.

Priority Area 1: Strengthen Angola's water resources management offices and frameworks as a key step toward building adaptive capacity.

- Strengthen hydrometeorological monitoring, which is crucial for water management and planning. INRH, INAMET, and GABHIC have worked to improve hydromet monitoring, but problems persist with the functionality of existing stations and data collection. All water utilities should start to systematically measure and record their water resources (e.g., aquifer, production springs, and river levels), to understand variability and detect impacts — including from other users.
- Strengthen licensing and registration of users. INRH is making progress on this with bulk water users, and with World Bank support (the PDISA2 project), a nationwide cadaster of users is being developed. Understanding resource use and demand dynamics through this cadaster will provide important

data for water resources planning, allocation, and management.

- Implement the bulk water abstraction tariff ("regime jurídico da taxa de captação de água do domínio hídrico") within the broader Financial and Economic Regime on the Use of Water Resources. Approval of this tariff will help promote the rational use of water resources. It doesn't apply to traditional and livelihood uses, so it will not burden poor households. PDISA2 will support pilot implementation in the Kwanza River basin, and the new RECLIMA project will do the same in the southern basins under GABHIC's administration.
- Develop technical capacity for modeling water resources and allocation dynamics. The systematic use of data to balance water allocation across competing demands will enable more sustainable use of water resources and will be crucial to shaping efficient responses to scarcity.
- Enhance the capacities of the Basin Administration Offices and support the creation of Basin Councils as stakeholder participation platforms. In 2021, the Government mandated GABHIC with managing all three southern river basins, but GABHIC still lacks the capacity to fully implement its mandate, and Angola's other Basin Administration Offices are still to be created.
- Clearly recognize the role of water in achieving key development goals in Angola. As a first step, this CCDR included an analysis of dynamics at the water-energy-agriculture nexus.

Priority Area 2: Adopt a comprehensive strategy for water storage at the basin level, integrating watershed storage, groundwater, and surface storage to maximize climate resilience.

- Promote the adoption of nature-based solutions (NBS) such as soil and water conservation measures, sand dams, and managed aquifer recharge to maximize the "sponge" effect of the watershed, in order to mitigate flood risks and store water for dry periods.
- Invest in groundwater exploration and ensure that existing data are shared, managed, and used to inform projects. Groundwater in Angola is poorly known, and thus poorly managed. Studies are needed on strategic aquifers in the South and nationwide. Angola also urgently needs to digitize and make use of the extensive HIDROMINA colonial archive of hydrogeology.
- Adopt a resilience-by-design approach to align surface water storage and other infrastructure investments with the unique characteristics and dynamics of each basin (Ray and Brown, 2015). Groundwater recharge and storage can be used conjunctively with surface water for flood and drought mitigation purposes.

Priority Area 3: Ensure the sustainable operation and maintenance of water infrastructure as a key element of resilience-building.

- Resources need to be channeled into operationalizing and maintaining existing dams. Technical capacities need to be strengthened, and each dam needs an instrumentation and surveillance plan, an operation and maintenance plan, and an emergency preparedness plan.
- Strong support from the Ministry of Energy and Water (MINEA) is

needed to strengthen coordination and management across levels of government and among agencies. Many irrigation dams are semi-abandoned and lack a designated owner or operator, and/or are in a cycle of neglect and disrepair.

Priority Area 4: Strengthen provincial water and sanitation utilities, and the regulator, to ensure that they are resilient to climate variability and shocks, and improve service coverage in urban and peri-urban areas.

- Provincial utilities have a clear and sustainable business model for service delivery, and they need to be strengthened. Provincial utilities have identified six key measures to improve their climate resilience: 1) protecting and monitoring watersheds and monitoring the resource, investing in knowledge, 2) diversifying water sources and conjunctive use of surface and groundwater, creating buffers to have options in times of scarcity, 3) developing drought preparedness and contingency plans, 4) reducing non-revenue water and increasing efficiency, 5) installing meters and creating customer registries, and 6) good operation and maintenance plans.
- Government efforts to connect urban and peri-urban households to the provincial utilities' supply networks must continue. Transitioning from tanker trucks to piped and metered supply has enormous benefits for beneficiary households and can also reduce GHG emissions.
- Continued support to the Electricity and Water Services Regulation Institute (IRSEA) will ensure well-regulated pricing and a healthy sector. IRSEA is working to reduce non-revenue water and promote an efficient and economic use of water, greater service reliability, and increased capacity to adapt to scarcity. Continue to explore public-private partnerships (PPPs) where they can work, selecting urban systems with a clear business model, well-regulated service, and a reliable customer base.

Priority Area 5: Invest to expand access to water and sanitation services for rural households and build planning and operating capacity in municipalities to reduce vulnerability to climate shocks.

- Household access to clean water is a key factor in resilience to climate change and disaster risks. The household's type of access to water for drinking has significant implications for distributional impacts of climate change on health, education and livelihoods.
- In rural contexts where vulnerability is highest, the consolidation and strengthening of sustainable operation and maintenance models of water supply systems is a priority. Investments in small solar- powered systems and manual hand pumps have proven to be more sustainable than those using generators, representing a win-win for adaptation and mitigation.
- It is important to strengthen municipal capacity to operate and maintain water points, frame local community management efforts, and coordinate backstopping support from the provincial level, in order to increase the functionality of water points. The implementation of Municipal Water Plans will promote the integration of local water supply with local management of

water resources and will improve preparedness to droughts and increase climate resilience for households.

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Secured Urban Water Supply for the City of Windhoek, Namibia

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Key Messages

- Water resilience is crucial for Namibia's economic resilience, particularly to ensure food security, as the country is highly vulnerable to water-related risks like droughts and floods.
- Closure of the industries in Namibia's capital of Windhoek due to water scarcity would create dramatic economic losses of about US$ 1.5 million per day on top of remarkable social consequences such as unemployment, poverty, and hunger.
- The Managed Aquifer Recharge (MAR) system in Windhoek has proven to be a cost-effective and dependable approach for augmenting water supply, meeting increasing demand, and mitigating the risks of water scarcity caused by droughts and climate change. MAR enabled farmers to irrigate larger areas and diversify their crops, resulting in increased food security and income.
- In order to ensure the most effective use of resources, investment in water infrastructure must be tailored to meet the specific needs of the country. Conducting a cost-benefit analysis and pilot testing before scaling investments are critical for success, as they enable the accurate

measurement of results and performance, providing access to crucial insights.

Namibia's Economy and Water Risk

Climate resilience is a crucial factor in ensuring economic resilience, particularly in the case of Namibia, a middle-income country located in southern Africa. The country is highly vulnerable to the effects of climate change, and water is at the forefront of its climate resilience efforts. With a population of 2.5 million, Namibia faces the challenges of increasingly frequent and severe droughts and changes in precipitation patterns. These challenges significantly impact the availability of water, agriculture, tourism, and other sectors that are crucial to the country's development. It is, therefore, imperative to address these issues urgently to ensure Namibia's sustainable development from both economic and social perspectives.

In 2022, Namibia's GDP was approximately US$ 23 billion, which translates to a per capita GDP of around US$ 9,200 per year (World Economics, 2023). The Namibian economy is heavily reliant on natural resources, particularly minerals and fish, which account for the majority of the country's exports. The tourism, mining, and agricultural sectors are the main contributors to Namibia's GDP, accounting for approximately 15 percent, 10 percent, and 4 percent, respectively (International Trade Administration, 2023).

Namibia is one of the most water-scarce countries in the world and highly vulnerable to droughts which have led to significant food insecurity with severe social and economic consequences. While agriculture plays a vital role in Namibia's economy, employing more than 50 percent of the labor force as compared to nearly 20 percent in tourism and only 3 percent in mining, the scarcity of water directly limits agricultural productivity, aggravating the issue of food and social insecurity (World Atlas, 2023).

Building economic resilience is imperative for Namibia, particularly in terms of ensuring food security, given the country's susceptibility to water-related risks such as droughts and floods. Namibia has been severely impacted by these challenges, As of October-November 2021, approximately 659,000 people, or a quarter of Namibia's population, faced crisis levels or higher of food insecurity, with 102,000 people in emergency conditions. This nationwide food insecurity was caused by a drought experienced in 2019, increased prices of food and non-food items between April-September 2021, and the impact of COVID-19 measures on supply chains and livelihoods (IPC, 2021).

It is important to recognize that water scarcity not only exacerbates food insecurity but also other social issues related to health, education, and gender equality. Women and girls, who are often the primary water collectors in rural areas, can be disproportionately affected by the time and effort required for water collection, limiting their access to education and economic opportunities (UNDP, 2022).

Namibia's water supply is greatly affected by the impacts of climate change on the country's limited freshwater resources and high variability in rainfall. The average annual rainfall in Namibia is currently only 350 mm, which has resulted in the country relying heavily on underground aquifers and the perennial river system for its water supply; however, these groundwater resources are facing significant pressure due to over-abstraction, climate change, and land-use practices.

The groundwater resources available in Namibia remain stagnant and are not expected to increase in availability. At the same time, there is an exponential increase in water demand in many economic sectors. This highlights the troubling pattern of rising water demand surpassing the supply in the country, despite the current installed capacity of water. This situation underscores the urgent need for Namibia to implement measures to manage its water resources sustainably and efficiently to avoid exacerbating the already critical water scarcity situation.

Managed Aquifer Recharge (MAR) as a Climate Adaptation Measure

Heavy rain and flood events as well as droughts threaten the livelihoods of the people either by a lack of water or by a surplus of water. In these situations, the storage of water in natural or built infrastructure is a key adaptation strategy. Aquifers are nature-based water reservoirs, whose functions can be artificially "enhanced" by MAR. MAR describes the intentional recharge of water to aquifers for subsequent recovery or environmental benefit. Thereby, it takes advantage of surplus water resources during flood periods through storage in the subsurface and its usage during dry seasons. In aquifers, water is well protected against pollution and evaporation, which is an important factor in arid and semi-arid environments and in comparison, with surface water reservoirs.

MAR could be very different technologies, based on infiltration, injection or dam structures. Aquifer Storage Recovery (ASR) and Aquifer Storage Transfer and Recovery (ASTR) are technologies which utilize injection wells to inject water into the aquifer. Other technologies, such as dune infiltration, infiltration ponds, percolation ponds, or rainwater harvesting, accumulate water on the surface and enhance the infiltration into the underground through longer retention times and an increased infiltration area. Other technologies require a greater effort including the construction of underground measures (e.g., underground dams or sand dams). These approaches create artificial underground water storages that have similar properties as natural aquifers. Rainwater, storm water runoff, river water, surface water, or even treated wastewater work well for MAR purposes. Depending on the water quality and on the recharge technology, additional water treatment processes are required before the water recharges the aquifer.

This innovative technology allows the usage of the underground storage capacities as a water bank, where water can be deposited when available and withdrawn when required. Thereby, MAR secures water supply, contributes to climate adaptation, and dramatically increases drought resilience. Further, enhanced water availability allows for more agricultural irrigation and thus increases agricultural yield, which supports food sovereignty and socioeconomic development. Another advantage is the reduced surface run-off that reduces the risks of flood events and erosion.

MAR in Windhoek

Windhoek is the capital city of Namibia and serves as the economic, political, and cultural hub of the country. Windhoek is the center of economic activities in Namibia and hosts the main share of the country's manufacturing activities, business and financial services (Mapani et al., 2023). According to the Namibian Statistics Agency's Quarterly Gross Domestic Product (GDP) report for the third quarter of 2021, the city of Windhoek contributed 21.6 percent to Namibia's GDP in that quarter. The services sector is the largest contributor to the city's GDP, accounting for 54 percent of the total, followed by trade and manufacturing sectors in 2022.

Aside from the challenges posed by climate change, increasing economic development and population growth in Windhoek puts further stress on the water supply. Murray et al. (2018) expects more than a doubling of the population from around 326,000 in 2018 to around 790,000 in 2050. While water supply in 2018 was around 27 MCM/year, in 2050 the demand is estimated to be around 50 MCM/a (Murray et al. 2018). These numbers indicate that a population increase of about 242 percent will be accompanied by a water demand increase of about 185 percent which implies a reduction of the per capita demand of around 24 percent from 83 m^3/year to 63 m^3/year. The closure of industries of Windhoek due to non-availability of water would bring dramatic economic losses of about US$ 1.5 million per day (Zheng et al. 2021). This could lead to huge social consequences such as unemployment, poverty, and hunger.

Due to these aggravated climate circumstances, the city of Windhoek already considered MAR in 1997 as an alternative to piping water from the distant Okavango River. First assessments and injection tests started subsequently. In 2004 NamWater, a public water utility in Namibia, conducted a study to investigate the feasibility of the MAR project including a cost-benefit analysis and a comparison with other alternatives as the construction of pipelines from the perennial surface water resources and the utilization of the far distant Tsumeb and Karst III Aquifers for emergency supply. Both alternatives are more expensive than the MAR approach. The water supply costs for the Tsumeb and Karst III Aquifer was estimated to be US$ 4.3/m^3 and for the Okavango pipeline US$ 35.6/m^3. The costs for the MAR scheme are US$ 2.0/m^3 (Tuinhof et al., 2012). Since the MAR scheme turned out to be the most cost-efficient option, injection started in 2006 with six injection wells. To serve the increasing demand and to secure water supply, twenty further wells were constructed in 2011 and twelve additional wells in 2016 (Murray et al., 2018).

The major share of the water supply for the city of Windhoek is stemming from three dam systems (Omatako Dam, Swakoppoort Dam, and Von Bach Dam) that store and accumulate surface water during the rainy season when the rivers are carrying water. The water is then purified and distributed into the supply systems. Surplus water that is not required for the direct supply of the city is injected into the Quartzite Aquifer after its purification. Additionally, a water treatment plant purifies wastewater up to drinking water standards and enables its injection and usage. The aquifer conditions and its overlying geological layers protect the stored water against pollution and evaporation, which is a big advantage in comparison to a long-term storage with dams. In times when no surface water is available, extraction wells pump the water out of the aquifer and distribute it into the water supply system to serve the populations as well as the industry and agricultural needs (Tuinhof et al., 2012). This scheme consists of pumps, pipelines, treatment systems, and wells. The operation from 2006 to 2013 directly contributed to an increase of the water level and thus allowed higher sustainable abstraction rates.

The aquifer infrastructure is currently owned and operated by the City of Windhoek, while the water supply infrastructure is owned and operated by NamWater. To establish, manage, and operate a MAR scheme, knowledge and expertise is required and needs to be addressed to ensure an optimized, long-term utilization of the available resources and infrastructure.

MAR Solution Saves Namibia Amidst Droughts by Serving as a Supply Backstop

From 2014 onward, Namibia has experienced a dry period with a reduction in precipitation rates, which also reduced the surface water availability. Thus, the recharge into the aquifer was intermittent and the groundwater levels dropped by around 40 meters because of the groundwater extraction. Without the recharge from 2006 to 2013, the abstractions would not have been possible at these numbers and the groundwater would now be at even lower levels. However, this shows that the scheme requires input, which is dependent on climatic conditions. If these conditions are not suitable for groundwater recharge (e.g., lack of precipitation and surface water availability), then the MAR scheme has to pause its operation until the conditions enable it. Thus, although the scheme improves drought resilience for the case of Windhoek, it should not be relied upon solely.

The MAR scheme of Windhoek functions as supply backstop, which ensures that the city is able to overcome prolonged drought periods that include a failure of surface water reservoirs. During rainy seasons, only 4 percent of the water supply comes from the aquifer and the main water source is surface water, which contributes around 76 percent to the water supply. This huge amount requires substitution during drought periods when no surface water is available.

Economic Potential

The MAR scheme lowers this risk of aquifer depletion significantly, further securing and improving the water supply situation. This allows the sustainable utilization of additional water resources and offers even further economic potential. For example, additional water for agricultural irrigation increases the agricultural yield and generates more jobs and higher incomes. The scheme also reduces the need to import expensive water from remote sources in the North. In addition, MAR has enabled farmers to irrigate larger areas and diversify their crops, resulting in increased food security and income (Bekchanov et al., 2016).

MAR as a Reliable and Cost-efficient Option

MAR has proven to be a reliable and cost-efficient water augmentation option to serve the rising demand and to avert the threat of water scarcity reinforced by droughts and climate change. The scheme is cost-effective due to its ability to utilize existing infrastructure and the fact that the water treatment process is less energy-intensive than other conventional treatment methods. This facility — the water bank of the city of Windhoek — under the current dimensions is expected to be able to provide security for three years as the sole water resource during drought conditions (Murray et al., 2018). According to Murray et al. (2021), expanding the water bank storage to 61–71 MCM would allow for the extraction of approximately 19 MCM of water per year, further enhancing the capacity of the MAR scheme to meet the increasing water demand and provide a reliable and sustainable water source for Windhoek.

Diversifying Water Investment Infrastructure

The integration of the MAR scheme with desalination can yield an economic internal rate of return (IRR) of approximately 94 percent, while the integration with the Okavango River transfer scheme can yield an IRR of around 68 percent (Murray et al., 2021). These IRR values significantly exceed the economic opportunity cost of capital of 10 percent. Moreover, this integration can provide improved water security and reliability for Windhoek, with desalination being capable of producing up to 26 MCM of water per year, as per the Windhoek Municipality's estimates. Therefore, the Windhoek MAR scheme's integration with alternative water supply options contributes to the city's water security and resilience.

Positive Net Present Value of the Project

To allow for future operation of the scheme, it is expected that the beneficiaries shall co-finance the operation over the economic lifespan of the project with US$ 115 million for operational costs and capital replacement over 30 years. This can be done via water expenses, which can be adopted according to the amount and usage. Despite a conservative set of assumptions, the project still yields a positive net present value, regardless of the choice of the water supply augmentation scheme in the future — whether it is desalination and transfer, or transfer from the Okavango River.

Conclusion and Way Forward

Namibia is grappling with a growing water scarcity issue due to severe changes in precipitation patterns and an arid climate — a condition only expected to worsen with climate change, making the country more susceptible to droughts. This poses significant challenges to the limited water supply, which will be exacerbated by the increasing water demand from population growth. Therefore, water resilience policies and programs are essential to withstand economic shocks and maintain socioeconomic well-being, given the country's vulnerability to water-related risks like droughts and floods.While agriculture plays a vital role in Namibia's economy employing more than 50 percent of the labor force, the scarcity of water directly limits agricultural productivity, aggravating the issue of food and social insecurity (World Atlas, 2023).

Windhoek is the center of economic activities in Namibia and hosts the main share of the country's manufacturing activities, businesses, and financial services (Mapani et al., 2023). Besides the climatic situation, the increasing economic development and population growth of Windhoek put further stress on the water supply. Murray et al. (2018) expect more than a doubling of the population from 2018 to 2050, which will be accompanied by a water demand increase of about 185 percent. The relationship between water resilience and economic resilience in the case of Windhoek is a direct relationship. The closure of the industry of Windhoek due to non-availability of water would bring dramatic economic losses of about 1.5 million USD/day (Murray et al., 2021). This leads to huge social consequences such as unemployment, poverty, and hunger.

The MAR scheme in Windhoek has demonstrated itself to be a reliable and cost-efficient water augmentation option to serve the rising demand and to avert the threat of water scarcity being exacerbated by droughts and climate change. The scheme has increased drought resilience and further secured and improved the water supply situation, allowing the sustainable utilization of additional water resources and offering economic potential. Conducting a cost-benefit analysis and pilot testing before scaling proved to be a critical success factor for the process. It enabled the accurate measurement of results and performance, providing access to crucial insights. Nevertheless, a MAR scheme is limited by the storage capacity of the aquifer and its requirement for water recharge, despite its effectiveness in buffering prolonged drought periods.

Windhoek aims to further diversify its water resources and promote integrated resource management to ensure a sustainable water supply for the future. This can take place by combining technological approaches and water management strategies. Along with the MAR scheme, which has already demonstrated reliability and cost-effectiveness, enhancing the water treatment plant's treatment and injection capacities could enhance the city's water supply. Further, Windhoek has integrated water-saving measures and rooftop rainwater harvesting technology, while also exploring options such as expanding the aquifer's storage capacity and increasing the water injection rates for aquifer recharge. Mapani et al. (2023) suggest drilling more deep wells to expand the storage capacity of the MAR scheme, and verifying if the water treatment plant can handle an increased capacity beyond its current 40 percent grey water recycling rate.

The drought index strategy is one of the implemented water-saving measures, targeting a 35 percent reduction in water usage. For the water scarcity and drought programs to be successful in Namibia, they should be staged for severity and intensity. Programs should also identify protected groups, ecosystems, and sectors and be revised regularly to incentivize adjustment to evolving extreme events.

Economic resilience requires active participation from both the public and private sectors. It is essential for the public sector and significant public finance, investment, and regulatory bodies to articulate a clear vision of the goals and strategies for economic resilience. Thus, integrated water planning and coordination across all sectors is vital for navigating these challenges. Overall, a comprehensive and urgent approach is necessary to address the challenges of increasing water demand and varying water availability resulting from expected climate changes.

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Sustaining the Inner Niger Delta Lifeline

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Key Messages

- Natural wetland systems in the Sahel provide significant economic value for millions, but this is typically not factored into sectoral water management investment decisions.
- Water resource management solutions of the past for food and energy security may not provide the desired security for the future.
- Decision-making around infrastructure investments to drive economic development need to be informed by a more holistic understanding of the economic pros and cons.
- With the unpredictable effects of climate change, ensuring livelihood and food security is not about (water) control but about flexibility to adapt: water resilience supports economic resilience.
- Solutions for the future need to be people- and ecosystem-based and need to be flexible, contextual solutions rather than fixated on time and place.

Introduction and Background

Wetlands provide significant economic value locally, nationally, and sometimes regionally. The Upper Niger Basin (UNB) and Inner Niger Delta are one large iconic, wetland system that extends across the Sahel delivering natural resource-based services to millions of people. Their health is dependent on the hydrology of the water systems that they are connected to, which typically drive seasonal flooding that in turn supports traditional and increasingly intensifying use of these services. Rice production, fisheries, and livestock raising are all typical uses that form the foundation of the wider economy in these areas. Growing population pressure, a strong need to drive socio-economic development based on increased water use, and growing impacts from climate change are driving growing water insecurity which is placing these systems at risk. Despite their importance, decision-making around water resource management remains rather sectoral and often takes insufficient account of the wider social and economic impacts.

Mali and Guinea are among the world's poorest countries, with persistent water, food, and energy insecurity. As in the wider Sahel belt of Africa, population growth is outpacing food production. Demand for food and energy is rising. To support their people and economy (GDP) Guinea and Mali want to increase their energy and food production and future security. Guinea and Mali are planning a new dam project on the Niger River in Guinea, and large-scale expansion of irrigation by the Office du Niger (ON) in Mali. Construction of the dam was announced in 2017, but since then little further action has been taken. At the time the case study was completed in 2020, the preferred dam size was 396 m high above sea level with a storage volume of 2.8 km^2 and a reservoir surface area of 287 km^2 (the medium option (Wetlands International, 2020)). The location was Folon, 30 km upstream from Fomi. This Fomi Dam is intended to take advantage of hydropower potential and to store and divert water for agricultural irrigation, providing a secure supply of water throughout the wet and dry seasons. An Environmental Impact Assessment has not been published yet and it is not clear if or how this plan will proceed.

This case summarizes the results of a study conducted by a Malian and international partnership including Wetlands International and others in close participative consultation with Malian government ministries and agencies. The study assessed the potential impacts of this infrastructure development according to the dimensions outlined above. It illustrates that economic resilience is also about water resilience in the Inner Niger Delta. The case shows the social and economic risks of designing and operating traditional, sectoral infrastructure in a context of water insecurity and a changing climate. It points to the need to make more strategic environmental assessments of such investments that take a holistic approach and embed the results in the wider economic sphere.

Climate Change

The landlocked countries Mali and Guinea already have significant variability in annual rainfall and experience regular droughts. For Mali, the annual mean temperature is 28 oC with a maximum of 51 oC and a minimum of 10 oC (MFA, 2018). Already the mean average temperature in Mali has increased by 0.7 oC and is expected to rise even further with differences per region and season. The frequency of hot days has not risen significantly (yet), but the frequency of hot nights did, except for during the winter. Rainfall has been decreasing since 2001 and the mean precipitation is changing. Mali has been getting less rain, ranging from 200 mm in the North (expanding to the South) to 1200 mm in the South (from averages previously above 1200 mm). The mean annual rainfall is projected to change further from -22 to +25 percent by the 2090s. However, with the current emission levels, we will reach 2 oC before 2050 (Climate Adapt, 2015). This means water availability becomes more unpredictable with large variations in time and place.

The Niger River Basin

The Niger River Basin covers a total area of more than two million km^2 and runs through nine countries. It is the main river artery of West Africa, flowing from the highlands of Guinea to its most northern point in Mali and back south to its delta outlet in Nigeria. It is the principal freshwater source in this semi-arid to arid Sahel region, making it crucial for the provisioning of a wide range of ecosystem goods and services along its route to many different beneficiaries. Even with some dams already in operation, the basin is still characterized by high natural variability, with extended periods of wet and dry years. Climate change and increasing temperatures are adding uncertainty to the amount of water that will be available in the future.

The Inner Niger Delta's (IND) functionality is integrally linked to the river flow arriving from the upstream river basin. It is characterized as a flood pulse driven system. The seasonal expansion and contraction of lakes and wetlands in the IND depends on the river inflow at the entrance of the delta: Ké-Macina for the Niger River and Sofara for the Bani River. The Niger River receives most of its runoff from rainfall in its headwaters in Guinea, located more than 600 km upstream. The Bani River contributes approximately 21 percent of the total inflow into the delta and is fed by precipitation in southern Mali and Cote d'Ivoire. Local precipitation in the IND is relatively low and contributes only a limited amount to the annual flooding cycle, meaning that the flood extent of the IND is largely dependent on precipitation in the upstream areas. In the wet season, from June to November, the IND transforms from an arid environment into a vast wetland landscape with few dry places at the height of the floods, before de-flooding again over several months.

Economic Contributions

In 2021, agriculture contributed around 33 percent to Mali's Gross Domestic Product and employed nearly 80 percent of Malians (many as subsistence farmers). The IND is a major economic asset in the Malian and regional economy. It is estimated to contribute approximately 8 percent of Mali's GDP (based upon estimates of its value to agriculture, livestock raising, fisheries, transport, and associated processing described below). In a country with low levels of education and scarce opportunities for non-agricultural employment (20 percent), millions of people and animals currently depend on the goods and services produced by the seasonal floodplain wetlands of the IND. Two million people (10 percent of the national population) live there permanently, and many others seasonally migrate there from dryland areas.

While covering only 1.6 percent of Mali's land area, the IND provides about 15 percent of national cereal production (Ministère du Développement Rural, 2016) 30 percent of rice production, 80 percent of fish production, as well as dry season grazing for up to 60 percent of Mali's cattle. Its unique location and ecosystem make it possible for farmers to grow crops farther north than anywhere else in the West African Sahel. Pastoralists and cattle from some neighboring countries move into the IND in the dry season, while fish from the IND are exported across West Africa. Primary and secondary production in the delta depends on the flooding (timing, extent), which has a significant impact on sustaining fisheries, agriculture, livestock, and housing. The flooding is rainfall, climate, and water management related.

Agriculture

For more than 90 percent of the farmers, agricultural production is important for subsistence. Farming in the delta is highly dependent on the combined effects of the rainy season and flooding periods. Cropping types, distribution, and yields are greatly defined by the date on which rainfall and flooding starts, the duration of the flooding period, the maximum water level, and the speed at which de-flooding occurs (Thom and Wells, 1987). Agriculture in the delta is mostly focused on rice and millet production. While rice is highly dependent on flooding and irrigation, millet and other important cereals such as fonio, maize, and sorghum are more dependent on rainwater availability.

Various irrigation techniques are used for rice production (30 percent of the national production) including: 1) rain-fed, 2) flood recession, where crops are planted on the moist floodplains after the flood recedes, 3) water levels being controlled in simple polders along the river, and 4) small-scale pump irrigation schemes (Pearce 2017).

Traditional floodplain rice production (yields) can vary greatly between years as it strongly depends on water availability as well as inundation zones and water depths (with an optimal depth 1–2 m). Rice production in the Mopti region can easily decline from about 400,000 tonnes in a wet year like 2010–2011 to about 100,000 tonnes in a dry year like 2007–2008. Compared to natural floodplain rice production, crop yields can be doubled when water is slightly managed, as with flood-controlled irrigation. In comparison, when land is fully irrigated the yield may be boosted up to six times. Normally, such a yield improvement requires higher agricultural inputs (e.g. fertilizer, labor, mechanization) and hence may also happen in the IND with the right sort of investment. However, at the same time it must be said that the water productivity (defined as the amount of yield produced per unit of consumed water) of irrigated land is under debate, with huge irrigation losses due to canal seepage and non-beneficial evaporation.

Fisheries

About a third of the population in the IND catches fish for either subsistence purposes or to sell on the market: 4 percent depend exclusively on fisheries, while more than 30 percent have a diverse livelihood with a combination of fishing, pastoralism, and/or agriculture. For fisheries, the Mopti region is most important (Schep et al., 2019). The delta produces 80 percent of Mali's fish and fish are exported across West Africa. Total fish trade in the IND is estimated to be between 10,000 and 50,000 tonnes and is also related to the flooding of the IND (Zwarts et al., 2005). The total value of fisheries (traded and auto-consumption) in the entire delta is valued at between 50 and 95 billion West African CFA Franc (FCFA) per year (Schep et al., 2019).

Livestock

The IND supports millions of cattle, sheep, goats, horses, and camels. It is highly productive for livestock, not only because of its size, but also because of its flood dynamics, grazing across the delta during the flood recession, through a practice known as "transhumance." Twenty percent of the 20 million goats and sheep and 60 percent of the five million cows in Mali are concentrated in and depend on the IND and its surroundings during the dry period (Wetlands International, 2019). The current economic value of livestock raising — including meat and milk production, animal sales, and leather — calculated for the regions of Mopti, Tombouctou, and Ségou, represents an annual total of about 250 million FCFA.

Socio-Economic Relevance

Housing, energy, and medicinal herbs

The vast majority of the local population collects clay to build and maintain their houses (94 percent). About 85 percent of delta inhabitants collect firewood to meet their own energy needs. Collection of herbs and tree-related products — natural products used in traditional medicine — is carried out by almost half of the respondents. Availability has decreased over the past five years (69 percent in the case of trees, and 87 percent for herbs).

Transport and navigation

Transport by boat is important for both commercial, social, and leisure purposes in the delta (e.g., access to local markets and medical, financial, and agricultural service providers). Passengers and freight are primarily transported by two different types of boat: the ferry and the pinasse (a traditional wooden boat). Ferries only operate during the wet season as they require a minimum of 3–4 m of water depth for navigation. The pinasses run through into the dry season until the water level becomes too low even for these smaller boats, which require around a meter of water. Based on the day rates and the average number of navigable days per route, the total annual value for fluvial transportation can be estimated at around 2.1 billion FCFA for the Koulikoro-Mopti route and 1.6 billion FCFA for the Mopti-Gao route.

Relevance for Biodiversity

The IND is one of the major wetlands in Africa, and the floodplain ecosystem sustains people and nature. The delta has exceptional ecological value and is a globally important biodiversity hotspot; it is designated as a Wetland of International Importance under the Ramsar Convention. Seasonal flood patterns are crucial in maintaining the biodiversity of the area (Klop et al., 2019; Wymenga et al., 2017a and 2017b). For instance, the area is of paramount importance to both resident and migratory bird species (Zwarts et al., 2006). At least 27 species of migratory water birds are seasonally present in very high numbers. The numbers of colonial breeding water birds in the central lakes are amongst the highest for wetlands in Africa. The IND's Acacia kirkii flood forests and the Acacia seyal forests at the fringes of the delta are home to high densities of migratory land birds, hosting many European species from the Red List of the International Union for Conservation of Nature (IUCN). The survival of wintering birds and reproduction of resident birds is directly related to the flood pulse dynamics of the IND, as expressed by the extent of the flooded area and the depth of the water. In turn, healthy ecosystems are central to the provision of the services that support community livelihoods and the delta's economy.

Office du Niger (ON)

The ON is a semi-autonomous government agency that administers one of the largest and oldest (since 1932) irrigation schemes in Sub-Saharan Africa. Water from the Niger River is diverted into a system of canals upstream of the IND at the Markala Dam, 35 km downstream of Segou and used to irrigate nearly 100,000 hectares. The production targets for 2017–2018 were set at one million tons of paddy rice, 350,000 tonnes of vegetables, 30,000 tonnes of corn, 47,000 tonnes of potatoes and 5,000 tonnes of fresh fish from floating cages, ponds, and rice-fish culture (if producers are provided with the needed certified seeds and quality organic and mineral fertilizers). ON is considered the rice bowl of West-Africa. Even so, the country still relies on imports of rice and wheat to avoid food insecurity (on average 540,000 tonnes per year). The livelihood situation of farmers in ON is not clear (no recent figures) but poverty seems less in ON compared to the national level. However, the average farm size is approximately 3.7 hectares with a low level of production due to a lack of fertilizer and poor water management. The bulk of the marketable surplus seems to come from a small number of farms with large irrigated areas. There also seem to be tensions between farmers and ON administration regarding (collective) water management and water user fees.

The Ambition

While Guinea has long desired to build the Fomi reservoir for electricity to support both its growing population and the energy needs of its mining industry, its most recent proposed design makes it multifunctional. A key secondary goal is to guarantee water for downstream irrigation expansion. Water released from the Fomi reservoir for hydropower generation during the dry season and then diverted at the Markala barrage would enable the ON to irrigate more land, supporting improved food security.

Fomi is therefore a key priority for the governments of Mali and Guinea and included as a priority investment in the Sustainable Development Action Plan of the Niger Basin Authority (NBA, 2007). In Mali the construction of Fomi is supported by the Ministry of Agriculture as a prerequisite to extend the irrigated area of the ON. To meet increasing demand for food, the Malian government proposed an expansion of the ON in the Study of the Agricultural Development Programme of the Office Zone du Niger, 2014–16 (PAHA IV). The goal of the ON is for it to become the rice granary for West Africa. Its current production of 740,000 tonnes across an irrigated area of about 1,300 km^2 generates 52 percent of national rice production. In total, the PAHA outlines the ambition to expand by an additional 3,300 km^2 over the coming 20+ years; 2,000 km^2 by 2025, 3,100 km^2 by 2035, and almost 4,600 km^2 by 2045. This ambition corresponds to an annual extension rate of 90 km^2. By comparison, over the last 10 years expansion has averaged 40 km^2 per year. Adding 3,300 km^2 will result in a significant increase in potential cereal production, projected at two million tonnes, including 1.2 million tonnes of rice — an increase of 58 percent. The total annual irrigated area will be even more as some areas will be cropped more than once a year. Based on these ambitions, the total irrigated area in 2045 will be about 5,400 km^2. The area earmarked for expansion is currently sparsely populated with livelihoods related to the flooding dynamics of the delta. With the expansion of the ON, these people will be displaced to other areas, but it seems unlikely that they will benefit from employment in the new development.

This ambition needs to be looked at through the lens of water availability. Over the period 1961–2000, only 67 percent of the current irrigation water demand of the ON would have been met, leaving a gap of 33 percent. Looking at the dry and wet seasons separately reveals that the deficits in the dry season are up to 43 percent and therefore on average quite substantial, whereas wet season irrigation supply deficits amount to only about 3 percent. Technically, the available water in the Niger River would allow the ON's expansion plans to be realized during the wet season. However, the plans also propose an intensification of crops such as off-season rice and perennial sugarcane in the dry season. A further extension of the ON's area in the dry season is not possible under current conditions and can only be achieved by either increasing irrigation efficiency or by supplying more water from the Niger River. Supplying more water by diverting the Niger River at Markala is not possible without the construction of a large new dam like Fomi for water storage upstream.

Impact of the Fomi Dam and ON Expansion on Production

Additional water infrastructure as currently planned in the Niger Basin will store and divert large volumes of water and hence have impacts on river discharges into the IND. The hydropower dam changes the flow regime by increasing discharges during the dry season and decreasing discharges during the wet season. In effect, it slowly flattens the flood curve and reduces the pulse that drives the delta's ecosystem and economy. The extent to which the flow regime is altered depends on the reservoir's dimensions and operations.

Operating Fomi purely for hydropower generation would increase the dry season discharge into the delta. Compared to natural flow conditions these would go up between 12 percent (small dam) and 156 percent (large dam). However, when this extra water released during the dry season from Fomi is diverted to expand dry season irrigation as planned by ON, the low flows entering the delta at Ké-Macina will be reduced below the level of natural flows. Taken together with the existing Sélingué Dam, this study showed that diverting water to meet the projected irrigation demands of the ON would reduce low flows by 58 percent in 2025, 91 percent in 2035, and 98 percent in 2045. In the case of a large Fomi Dam, the low flow would change from a 156 percent increase under 2015 irrigation conditions to a 78 percent reduction under 2045 irrigation projections compared to natural conditions. This reduction in low flows increases the risk from stagnant water bodies in the IND and could dry up the delta significantly.

History shows that a complete dry up of the IND would lead to a collapse of the ecosystem and food production. Projections also show that the assumption of double cropping in the ON would not be sustainable with available water frequently being insufficient. These changed inundation dynamics will determine the total amount of ecosystem services that can be provided in the delta. The median flood peak would be reduced to a level comparable to 1987 — the year with the second-lowest peak simulated in the period 1961–2000. This resulted in an inundation of 350 cm and flood extent of 10,000 km^2. In the IND, it would compromise the productivity of the ecosystem for the population. Fisheries in the Mopti region would decrease by 24 percent. The amount of cattle, sheep, and goats that could be sustained in the region would decrease between 5 percent and 13 percent. For the more than two million people living in the IND, this would mean diminished economic prospects and increased food and water insecurity. The number of navigable days with ferries and pinasses in the delta would on average go down by 17 percent between Mopti and Koulikoro and even up to 33 percent between Mopti and Gao. A smaller delta also provides less habitat for flora and fauna. Secondly, with livelihoods providing less food security, people resort more to wildlife hunting, leading to huge stress on local populations of birds and mammals and on areas like flooded forest for construction, energy materials, and traditional medicines.

Based on recent hydrological model simulations it is evident that if the Fomi Dam project is built and ON irrigation is expanded as planned, the inundation dynamics in the delta will see a shift towards a higher number of drier years compared to the current situation. The frequency of very dry years is estimated to increase from 24 percent to 29 percent. Irrigation expansion will have an even larger impact. If more water is diverted for irrigation by the ON, the frequency of very dry years could increase to 42 percent — almost one out of every two years.

The probability of disaster years will also increase substantially. In the current situation, these occur once every 50 years. In the scenario with an operational Fomi Dam and expanded ON irrigation, the frequency increases by a factor of five — to once every 10 years. In a worst-case scenario, the combination of a Fomi Dam, expanded irrigation, and a very dry year would reduce peak flows below levels ever seen and completely dry up the IND, leading to a complete collapse of the ecosystem and affecting the two million people whose livelihoods are based upon this ecosystem. It is highly unlikely that households in the IND could move to this new irrigated area in ON and profit from the development. This would be a humanitarian disaster with famine and widespread migration.

Impacts of Fomi Dam on Migration and Conflict

There are three livelihood strategies for people in the IND: intensification, diversification, and migration. The local and regional context determines whether (seasonal) migration is negative or positive for the economy, but it does put stress on families and livelihoods.

Life in the IND has always been a delicate balance including adjusting to the natural variation of the region's climate and its implications for water security. When changes to the IND's service provision affect the livelihoods and local economy, people will be forced to consider alternatives including migration and/or increased competition for natural resources. The sustainability of livelihoods for fishers, farmers, and pastoralists in the IND depends greatly on whether they have access to and control over various types of assets like the water, fish, soil, and fodder provided by the wetlands, along with other assets like technologies, information, and financial resources. Farmers also need access to fertilizer (either in the IND or in ON). Access to assets strongly influences which strategy people choose to either maintain or boost their livelihood. For each of these three livelihood strategies, migration increases for every decrease in water level in the delta. A considerable share of farmers and fishers would abandon their occupation and permanently migrate to a different region, country, or continent if they considered the water level to be too low. In a situation with maximum water levels at Akka above 500 cm (a constantly a wet year), less than 10 percent of interviewed farmers said that migration would be a likely strategy to sustain their livelihood. With decreasing water levels, more and more farmers consider migration a viable sustainable livelihood strategy, going up to 20–40 percent in cases of maximum water levels of 350 cm (a very dry year).

Pastoralists are less influenced by the water level. At the lowest level of 350 cm, 16 percent of pastoralists expressed a willingness to permanently out-migrate, while more than 40 percent of the fishers of Tenenkoun and Ké-Macina agreed that permanent outmigration was the most viable strategy under these conditions. In scenarios that result in a higher occurrence of dry, very dry, and even disaster years, consideration of permanent outmigration as a preferred sustainable livelihood strategy increases. In a scenario with a large Fomi Dam and ON irrigation at 2045 projections, 21 percent of farmers, 24 percent of fishers, and 10 percent of pastoralists would be willing to out-migrate.

Tensions and conflicts arise when communities seek to use the same water and land for different livelihood seasonal strategies (e.g., farming, herding, fishing). This leads to widespread discontent and provides fertile ground for extremist groups to exploit. The water stress caused by the effects of climate change, overexploitation, and upstream management decisions results in behavioral change amongst communities in the delta as they seek new coping strategies, which in turn trigger more tensions and conflicts, and is detrimental to production and the economy.

Lessons from the Past for Climate Adaptation

The Upper Niger Basin has historically experienced large annual and decadal variation in rainfall and resulting fluctuations in river discharge. The 1960s are considered wet years characterized by high precipitation and river discharge. From 1969–1992, the Sahel suffered the Great Drought (known locally as La Grande Sécheresse). During this prolonged drought, the flooded area of the IND averaged only 11,000 km^2. People and nature could not adapt. The drought triggered severe famine in the Sahel and increased desertification. In 1984, the IND only reached an inundation of 8,000 km^2, or one-third of its maximum range. While the IND was a relative haven during the drought compared to the rest of the Sahel, the carrying capacity of the ecosystem and its services collapsed under the pressure of too many people and livestock and too few resources. Most of the delta's flood forests suffered overexploitation and some were entirely destroyed. Also, the production of bourgou, a staple fodder for livestock that grows with floodwater, was disturbed when there was little or no rainfall to initiate its growth ahead of flooding. Many cows died and herders lost more than half their cattle due to reduced food resources and the reduction of the inundated area.

Climate change is likely to result in increased temperatures for the region along with unpredictable changes in precipitation. Simultaneously, the population is growing. A new drought period would affect a larger population with more destructive consequences.

Synthesis: Water Resilience for Economic Resilience

The Inner Niger Delta and wetland systems like this across the Sahel have significant social and economic value from local to national scales. A key characteristic of the IND is its seasonal dynamics that underpins the economy. The annual cycle of flooding and de-flooding is integral to the IND's regional economy, which is based on farming, fishing, and pastoralism and supports significant biodiversity and a diversity of livelihood strategies (including seasonal migration). Increasing food and energy production and security in the Sahel is essential to address the needs of the growing population. Because water plays such an important role in sustaining livelihoods, new water infrastructure should also be "conflict-sensitive" (Wetlands International, 2019). While irrigation can provide water security for agriculture and will continue to be a major part of the mix of measures to safeguard food security, the times are changing. Solutions that worked in the past will likely not work in the future due to climate change and its disruptive impact on people, ecosystems, and water infrastructure operations. Climate change will increase local temperatures, the variability of rainfall, and the magnitude of extreme weather events (e.g., droughts and floods).

The current strategy in the IND, predominantly focused on the realization of large-scale irrigation and hydropower, will bring undoubted benefits but also carries substantial risks and associated costs. Foreseeable consequences range from diminished livelihoods and biodiversity loss to an increase in instability, heightened risk of conflict, and increased outmigration from the region. Safeguarding and optimizing the role of the IND needs to be central in future thinking around planning and investment. Furthermore, this demands measures to ensure that water-related investment, strategy, and policy work to maintain such critical natural systems as part of development solutions rather than risking depleting them and creating risks and problems. Currently in Mali there is some limited consultation on such initiatives, but they are predominantly sectoral driven, and environmental impact assessments — when they are carried out — do not expose the full range of issues and implications to the economy and society as a whole.

People living in the IND have traditionally used a combination of intensification, diversification, and (seasonal) migration. The existing culture of diversity in livelihood strategies is also the basis for an adaptative, flexible coping mechanism to build on. A holistic, ecosystem-based and human-rights based approach to integral water management of the IND plus improving ON's irrigation efficiency and using less water-intensive crops may underpin Mali's development and food security ambition and provide a lifeline to the people in the IND.

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South Africa: The Resilient Transition

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Key Messages

- South Africa is a water-scarce country, and climate projections show a worsening trend due to rising temperatures and shifting rainfall patterns in the future. The country faces an acute water scarcity challenge, especially in the Western Cape province.
- Despite its scarcity, water is poorly managed. Water loss costs municipalities about R10 billion each year. Moreover, 40 percent of the country's wastewater is untreated, and a significantly low proportion is reused.
- To address the country's water challenges, the government has adopted new practices for better water resources management, improved water supply and sanitation services, and alignment of SA's water policies and strategies with climate change impacts. These include reforms in policy, investment, and demand management.
- The most important costs for adaptation measures will be in building a resilient water system, followed by resilient cities and transport. Financing requirements in the water sector will be higher

between 2022 and 2030 than in the next decades given the urgency to address SA's water challenges up front.

- Given the "public goods" nature of the necessary investments, there is a need to improve public investment management and increase coordination across different tiers of government.

Introduction

South Africans are increasingly exposed to climate-related risks. In 2021, the country declared its third national state of disaster for drought in the last four years, and Durban was devastated by major floods in 2020 and April 2022. These climate risks are projected to worsen in the future. Several key economic sectors are particularly vulnerable to climate shocks, including agriculture, infrastructure, and tourism (especially nature-based tourism), as are several cities. Climate risks disproportionately affect poor people, who live in locations prone to disasters, have more fragile assets, do not have the resources to adjust their lives to changing climate conditions, and are underrepresented in decision-making processes.

Building a resilient economy will require significant investments in the water, road, and agriculture sectors as well as in cities. The Country Climate and Development Report (CCDR) estimates that these investments will amount to about 1.3 percent of South Africa's (SA's) GDP per year or R2.4 trillion in net present value between 2022 and 2050. The necessary investments need to be implemented early to lower the country's vulnerability. To reduce these costs, the government could adopt structural reforms to improve the efficiency of public spending and incentivize private sector investments in green and climate-smart projects.

Resilient Water: Vulnerabilities and Adaptation Measures

SA is a water-scarce country, and climate projections show a worsening trend due to rising temperatures and shifting rainfall patterns in the future. With mean annual precipitation of just 450 mm and over 98 percent of its freshwater resources already allocated for different uses, the country faces an acute water scarcity challenge, especially in the Western Cape province. The water scarcity index is expected to increase under all future climate scenarios, with the largest negative impacts in the Orange, Limpopo, Vaal, Berg, and Olifants Rivers.

The reliability of bulk water supply is no longer assured for main urban centers. Key cities and towns such as Johannesburg, Cape Town, Randburg, and Pretoria are all in areas of projected high-water scarcity. The economic costs and negative implications for living conditions, especially for vulnerable groups, can be significant for the country. Another source of vulnerability is the country's heavy dependence on water transfers from Lesotho.

Despite its scarcity, water is poorly managed. Agriculture accounts for the largest share of water use (57 percent), followed by industry (around 21 percent) and municipalities (21 percent). On average, SA loses about 35 percent of its municipal water (against a global best practice of about 15 percent) and about 24 percent of its water allocated to irrigation. This water loss costs municipalities about R10 billion each year (World Bank, 2019). Moreover, 40 percent of the country's wastewater is untreated, and a significantly low proportion is reused. More than half of all wetlands have been lost over the past decades, and one-third of the remaining ones are in poor condition (DEFF, 2021).

Although SA is a water-scarce country, some areas are prone to flood risk. This is projected to intensify in future, especially in the southern and eastern parts of the country. In 2021, all nine provinces were adversely affected by flooding. And in 2022, the storms and flooding in KwaZulu-Natal killed over 450 people, destroyed properties, caused a crisis of water supply and sanitation provision (and associated impacts on public health), and disrupted commerce due to impacts on Durban's port and highways/railways linking the port to the rest of the country. The damages were estimated at over R17 billion or 0.3 percent of GDP.

Investments and Policy Reforms Required for a Climate-resilient Water Sector

To address the country's water challenges, the government has adopted several policies and strategies that call for better water resources management, improved water supply and sanitation services, and alignment of SA's water policies and strategies with climate change impacts. These policies and strategies recommend a series of interventions that will support adaptation, including:

- Policy and regulatory reforms: Various strategies have proposed monitoring climate-related data, sharing this data across several tiers of government and non-governmental organizations and citizens, and processing and using this data to guide planning and decision-making, including early warning systems and the development of comprehensive plans to respond to disasters. The importance of coordinated implementation of these policies and strategies has also been emphasized.
- Investments in supply augmentation: To address the projected water demand gap, augmentation measures include harvesting water, importing additional bulk water from outside SA, increasing groundwater use, and introducing unconventional water supply options such as treated wastewater reuse and desalination.
- Demand management measures such as conserving water, importing water-intensive goods, and recovering water from acid mines are also needed.

Transitioning from coal to cleaner energy sources can help augment water availability, resulting in both climate and development benefits. About 7 percent of SA's total water use is to cool down coal-fired power plants and wash coal, so the decommissioning of these plants and the closing of coal mines will result in additional available water. This "saved" water could be allocated to different economic sectors according to the social and environmental benefits they generate for society.

The private sector has a limited role in SA's water space. While the private sector is active in major bulk water supply schemes, its role in municipal water supply services is limited in comparison with other middle-income countries. Efforts are underway to improve the enabling environment for public-private partnerships (PPPs) in the broader water supply and sanitation value chain, but implementation remains slow.

Adapting to climate change and building water resilience will be costly but will bring significant benefits. The proposed actions under the National Water and Sanitation Master Plan require incremental investments of about 0.4 percent of GDP per year, or a cumulative cost of R720 billion in net present value over the period 2022–2050. This figure is in line with the projected costs for the country to meet Sustainable Development Goal 6 (sustainable access to water supply and sanitation), demonstrating the inextricable link between climate resilience and good development outcomes (DWS, 2023).

Recommendations

- Reduce both technical and financial losses in the system. This starts with fixing dilapidated pipe networks and improving municipal water supply governance, which requires improvements in coordinated planning by the national, provincial, and municipal authorities and strong links with the sectoral strategies for agriculture and urban development. On the supply side, existing plans should account for future climate change impacts on the availability of water resources and changes in water demand.
- Manage water demand through pricing strategies. The government could consider forms of water pricing that incentivize more efficient use in agriculture and contribute to more assured municipal supplies. For example, linking water pricing to increased investments in irrigation and other infrastructure could lead to an improved allocation of resources.
- Close the water service gap and reduce flood risks in poor urban and rural areas, which are vulnerable to water scarcity and extreme weather events. Over three million people still do not have access to a basic water supply service and 14.1 million people do not have access to safe sanitation. Poor households are disproportionately vulnerable to flood risks. Interventions should include mapping and characterizing communities and locations vulnerable to projected shifts in water demand and floods and improving infrastructure in these vulnerable locations through land-use planning, development controls, consideration of climate risk in designs, and use of green infrastructure, including nature-based solutions (NBS).
- Strengthen links between the energy transition and water use. Transitioning away from coal will free up water resources for other activities. The government could plan in advance how to optimize this by assessing the volume of water that can be reallocated, the mechanisms to reallocate it to main users, the investment costs, and the timeline.
- Develop innovative financing solutions for water-resilient projects, including through PPP initiatives. The private sector can complement the government's role in the water sector. However, the enabling environment needs to be improved to promote

Resilient Agriculture: Vulnerabilities and Adaptation Measures

Although agriculture only accounted for 2.9 percent and about 5 percent of SA's GDP and employment in 2021, this sector has a central role to play in poverty eradication and inclusive development. Rural areas report a higher poverty rate than urban centers, and a resilient agriculture has significant implications for the country's food security and exports. There are significant opportunities for expansion and diversification of agricultural activities, including in the Eastern Cape, Limpopo, and KwaZulu-Natal provinces, which are home to a large proportion of smallholder farmers, who are among the poorest in the country.

Agriculture is vulnerable to climate change. The combination of higher temperatures, seasonal variations, and lower precipitation has led to water scarcity, land degradation, and greater exposure to pests. Smallholder agriculture, which is predominantly rainfed, is particularly vulnerable to climatic shocks and natural disasters. A 2019 report by the South African Insurance Association indicates that 42 percent of farmers incur losses resulting from droughts, followed by 29 percent from storms and 28 percent from floods (SAIA, 2019). Smallholder agricultural development is hampered by large unmitigated climate risks. As a result, yields have been negatively affected and could decrease by 25 percent in the most vulnerable regions. The demand for irrigation is also projected to increase by 15–30 percent under the extreme climate scenario (SSP3, dry) over the next decades.

SA's long coastline and rich marine biodiversity provide opportunities for expanding fisheries and aquaculture, but are also exposed to climate change. SA's fisheries sector accounts for only 0.1 percent of the country's GDP but the commercial sector employs over 27,000 people directly and an estimated 81,000 to 100,000 people indirectly, while the subsistence sector employs 30,000 fishers. Most fishing activity takes place along the western and southern coasts.

Climate change affects SA's fisheries and aquaculture sectors differently. Marine fishery stocks are already dwindling due to overfishing, but a changing climate exacerbates these pressures. Climate change impacts on fisheries include changes in the spatial distribution of species and lower abundance and productivity of marine resources. This makes fisheries management less effective. Overall, fisheries production is projected to decline by 13.3 percent by 2030. In contrast, the aquaculture sector is moderately vulnerable to climate change and is projected to grow at 61.8 percent per year over the next decade.

Investments and Policy Reforms Required for a Climate-resilient Agricultural Sector

The government has anchored its strategy of building a climate-resilient agricultural sector on two key priorities: 1) water management, including irrigation expansion and measures to improve water-holding capacity such as watershed management and soil and water conservation activities and 2) climate-resilient infrastructure, covering transport and electricity. Beyond investment, additional support through grants and subsidies may be necessary to promote research and development in greener and more resilient agriculture such as heat- and disease-tolerant breeds, dry farming, and other climate-smart agronomic practices.

Nevertheless, weak alignment between several policies and strategies and limited coordination across different agencies and tiers of government during implementation have led to suboptimal outcomes in climate-smart agriculture and smallholder farmer development.

Another priority for the government is to expedite its land reform policy and secure land tenure for smallholder and emerging farmers. This should increase opportunities for these farmers to own productive assets and their motivation to invest in irrigation schemes and other infrastructure, as well as sustainable land management and related climate-smart measures.

Such initiatives should be accompanied by capacity-building programs, including financial support, for these farmers and their communities. The private sector has also launched a few initiatives to help farmers adapt to climate change and so complement the government's efforts.

The estimated investment needs for adaptation measures in agriculture are about 0.2 percent of GDP or R453 billion in net present value between 2022 and 2050. About 50 percent of these costs will arise from investments in irrigation programs, while the remainder will be divided between retrofitting and new investments in transport infrastructure (45 percent) and research and development (5 percent). These figures are aligned with those from the International Food Policy Research Institute (Sulser et al., 2021).

Recommendations

- Reduce the risk of water stress for farmers. This will require increasing investments in irrigated agriculture and reducing costs of existing schemes. Potential interventions include installing solar-powered rainwater-harvesting ponds, rehabilitating smallholder irrigation schemes, and expanding existing commercial irrigation, including public schemes and farm-led irrigation within hydrological limits. Watershed-based interventions will increase water retention and build climate resilience more broadly through pasture improvement, landscape restoration, biomass enterprise development, and community agroforestry. These initiatives can also generate job opportunities for unskilled laborers. The co-benefits could be maximized through better intergovernmental coordination and alignment of fiscal transfers and subsidies to local governments, communities, and farmers.
- Accelerate security of land tenure among smallholder and emerging farmers by improving land transfer mechanisms, ensuring new landowners have the necessary skills and support to succeed. Strengthen land administration to expedite transfer of ownership and security of tenure, and facilitate partnerships between smallholder and emerging farmers, and larger commercial farmers along the agriculture value chain.
- Consider carbon credits for generating revenue for farmers. Using carbon credits would require farmers to adopt green standards and guidelines and a credible monitoring, reporting, and verification mechanism. Building on the recently published green finance taxonomy, the government can identify a set of climate-smart measures and practices in agriculture that could be linked to carbon credits. Those could become a source of income for local rural communities through a transparent trading system as experimented, for example, in Australia and Kenya.
- Further promote cooperation between the public and private sectors. Partnerships should be considered for infrastructure projects such as water distribution and other joint activities, including

testing and liming soil to ensure more effective fertilizer use, implementing conservation tillage, and preparing grazing plans for communal livestock investments.

- Research and develop heat-tolerant breeds and seed varieties, strengthen animal and plant nutrition and health to deal with changes in disease incidence, increase use of digital technologies to improve yields and increase efficiencies, and adopt regenerative agriculture as important factors for increasing the climate resilience of this sector.
- Promote inclusive agricultural insurance programs. Such programs could support farmers by: 1) serving as a proxy for collateral for farmers to access credit and 2) protecting them against climate catastrophes. Good statistics and information tools are needed to develop adequate insurance products and their pricing, including by collecting real-time data with automated weather stations and upgrading agricultural statistics portals.
- Strengthen the resilience of the fisheries and aquaculture sectors. This could include: 1) adopting new adaptive management measures (such as feedback control systems governed by rules), 2) empowering fishers to participate in decision-making and management processes, 3) developing early warning systems, and 4) improving energy infrastructure to maintain diurnal temperature variation of intensive aquaculture production systems.

Resilient Cities: Vulnerabilities and Adaptation Measures

South African cities are highly vulnerable to floods, urban heat, and droughts. These climate risks are expected to worsen in the future, with up to 19 percent of the urban population exposed to flooding by 2050. Concurrently, some metropolitan areas could experience a 10 percent reduction in precipitation, increasing the likelihood of major drought episodes. The damages from climate risks could be substantial as about two-thirds of the population is urbanized, and industrial and service activities are highly concentrated in urban centers.

Recent experiences from the Cape Town “Day Zero” drought and recurrent flood damage in KwaZulu-Natal have demonstrated that damages are localized, including within cities, with poor households in townships and informal settlements disproportionately affected. Those damages are compounded by inadequate urban spatial planning, infrastructure development, and energy policies. Urban policies that promote transport-oriented densification and green infrastructure could reduce damages. A recent study estimated that the exposure of the population to flooding and landslides will be reduced, by 10 percent and 2 percent, respectively, in SA’s six major metropolitan areas if such urban policies were implemented (World Bank, 2022).

Investments and Policy Reforms Required for Climate-resilient Cities

The general framework for coordinated planning and implementation of climate actions in cities is guided by the National Climate Change Response Policy (2011), the NDP, the Spatial Planning and Land Use Management Act (2013), and the Integrated Urban Development Framework (2016). Moreover, NT’s Cities Support Programme was developed to support the scaling up, alignment, and integration of adaptation strategies in cities’ investment plans for infrastructure and service delivery. At the city level, most metropolitan areas have developed climate action plans and have policies, strategies, pilots, and data for promoting sustainable, resilient, and inclusive urban development.

To build more resilient cities, the government is focusing on better land-use planning and compact city development. Such an approach promotes shorter traveling distances and better access to municipal services, thus facilitating social inclusion. It reduces water consumption and the costs of waste management. Better land-use planning and densification policies can also help avoid developments in risk-prone areas, while green infrastructure is expected to build resilience and minimize infrastructure damage and disruption of services during flooding. Digitizing city infrastructure and transport management systems can also help to reduce wastage and improve efficiency. Finally, investments in densification and green infrastructure offer additional social and environmental benefits, such as low traffic congestion, clean air, job creation and lower costs of providing services for municipalities (C40, 2022).

Achieving compact urban growth will require improved coordination. At the local level, South African municipalities are constitutionally mandated to provide a wide variety of services (such as electricity, water, sanitation, solid waste, and local roads construction and maintenance), but many have insufficient funding and human resources to fully develop climate-smart projects. They will require both financial and technical support from the national government.

Implementing climate-smart policies in SA's six metropolitan areas will cost an estimated 0.3 percent of GDP per year or R581 billion in present value between 2022 and 2050. These estimates assume that the incremental cost of adaptation policies is approximately equal to 20 percent of the total cost of urban investments (R2.6 trillion in net present value) required over the next 25 years.

Recommendations

- Align climate change and development policies between national and municipal authorities. Building resilient cities should be the responsibility of local authorities, but many measures will require coordination with neighboring provinces and the national government. Expediting the implementation of the country's Integrated Urban Development Framework will provide an inclusive governance framework for decision and implementation processes.
- Integrate spatial planning in adaptation strategies to reduce vulnerabilities for the population and lower the cost of adaptation measures. The World Bank Group has developed an urban planning tool to assess exposure to risks and city-wide impacts of climate resilience policies that local government technical staff can use.
- Strengthen urban resilience to floods and droughts. The main climate risk for urban centers is associated with water management and access, which will require retrofitting existing infrastructure and investing in new projects (if possible, in partnership with the private sector). Improving water demand management will require closely engaging with local communities through education and information programs and using incentives/sanctions to promote responsible behaviors.
- Develop people-centered interventions by engaging local

communities in determining climate adaptation priorities, including disaster risk management and evacuation procedures. A key people-centered intervention is the NT's City Support Program's township economic development program and the Department of Cooperative Governance and Traditional Affairs' small town regeneration program, both of which promote houses and neighborhoods that are livable and climate resilient.

The Macroeconomic Damages of Climate Risks and the Costs of Adaptation

To estimate the overall economic damages from climate risks, a standard macro-structural model was adapted by introducing four damage functions (Burns et al., 2021). These functions include: 1) built up capital and land asset damages due to floods, 2) rainfed crop damages due to changes in temperature and precipitation, 3) livestock damages due to heat stress and availability of grazing pasture due to drought, and 4) labor productivity impacts due to heat stress. While these functions incorporate some of the major risks faced by SA, they are not exhaustive as they do not account for the broader impacts of water scarcity on the economy, the potential damages on human capital (education, health, and social protection), or possible economic tipping points. By contrast, the damages from tropical storms and rising sea levels have not been incorporated because they are not expected to significantly impact SA's economy before 2050.

While five major global climate scenarios (Shared Socioeconomic Pathways (SSPs)) were selected to assess SA's future climate projections, the results are only presented for the pessimistic scenario—SSP3- 7.0, dry. The overall damages derived from the forecasting model are expected to be relatively limited for SA's economy, amounting to around R1.5 trillion in net present value between 2022 and the end 2050, or on average 0.8 percent of GDP. They will, however, increase over time, reaching up to 1.2 percent of GDP per year between 2040 and 2050. Climate damages related to heat shocks on labor productivity account for 80 percent of total damages across the four channels considered.

The relatively moderate vulnerability of SA's economy to climate risks is explained by its moderate exposure to sea-level rise, at least until 2050, and to tropical storms. These two risks tend to account for the biggest economic damages globally. In addition, agriculture accounts for only 2.9 percent of GDP in 2021, when it is a major economic sector in many developing countries. Finally, the country benefits from relatively resilient infrastructure and good-quality buildings.

However, these overall estimates of damages mask significant variations both geographically and across income groups. The spatial distribution of damages from climate risks will be uneven across provinces. Damages are also expected to be bigger in major urban centers, where most economic activities and the population are concentrated, with the poorest households disproportionately affected.

The CCDR used two complementary methodologies to estimate the costs of adaptation measures needed to address the country's climate vulnerability. First, using a top-down approach following a methodology developed by the World Bank Group, the annual financing requirements to upgrade the country's assets are equal to 3 percent of their value (Hallegatte et al., 2017). The adaptation cost following this methodology would amount to about R1.8 trillion in net present value over the period 2022–2050, or an average of 0.93 percent of GDP per year. Second, using a bottom-up approach by adding all the financial requirements estimated for water, agriculture, cities, and road infrastructure in the preceding sections. Using this approach, the total adaptation cost would amount to R2.4 trillion in net present value between 2022 and 2050, or about 1.3 percent of GDP per year. While these two figures should be interpreted with caution, they are quite similar.

The bottom-up approach indicates that the most important costs will be in building a resilient water system, followed by resilient cities and transport. It also shows that the financing requirements in the water sector will be higher between 2022 and 2030 than in the next decades given the urgency to address SA's water challenges upfront.

Reforms in fiscal policy and management can reduce the cost of investing in adaptation. Given the "public goods" nature of the necessary investments, there is a need to improve public investment management and increase coordination across different tiers of government to enable the emergence of economies of scale in the design, implementation, and resourcing of green infrastructure projects. Horizontal coordination at both the national and local levels is necessary to align annual budget planning with medium-term investment planning, and recurrent expenditure (for operation and maintenance) with capital expenditure. Using internationally compatible guidelines and a taxonomy for adaptation projects improves their transparency and comparability and helps mobilize resources. New investments from existing and new firms can be encouraged by making climate information, associated risks, and instruments to address them available, promoting disclosure of information, lowering barriers to entry, and using the right pricing signals.

These measures should be complemented by targeted actions on climate-related investments, including:

- Conducting periodic risk assessments of public assets and contingent liabilities owned by general government institutions and developing the use of markets and insurance instruments.
- Improving the efficiency of climate-resilient public investments by: 1) introducing performance indicators for the allocation of fiscal transfers from the national government to provincial and local governments, 2) systematically tagging and monitoring those expenditures in the budgets of the national and local governments, and 3) evaluating projects using a social welfare-equivalent discount rate (in contrast to a market-based discount rate) to enhance rapid interventions.
- Adopting green public procurement procedures such as construction standards or land-use regulations that explicitly account for climate risks.
- Enhancing the PPP legal framework to create incentives for greater private sector participation in climate resilient-infrastructure projects by allowing risk-sharing on investments in new technologies, innovative business practices, and climate-smart performance-based contracts.
- Considering tax incentives to stimulate private operators to spend more on improving the resilience of their own assets or to expand their investments for the well-being of the community through corporate social responsibility measures.

SA has already initiated some of these measures, but it is important to operationalize them at scale. In addition to these cross-cutting fiscal measures, the government can use financial sector policies to stimulate more and better climate-resilient investments from both the public and private sectors.

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Managing Afghanistan's Water Crisis for Economic Resilience

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Key Messages

- Afghanistan, a country with high political instability, suffers a huge water shortage problem owing to ongoing conflict, poor institutional management, and climate change.
- Climate change is worsening the already severe water scarcity issues in highly populated urban areas like Kabul, Kandahar, and Hirat.
- Water resilience is crucial for Afghanistan's economic resilience, but the country's water sector still faces challenges such as financial limitations, lack of data, poor coordination, and security issues.
- Over the last 20 years, the role of ODA financing in the water sector was remarkable, with Afghanistan receiving over US$ 4 billion in ODA to improve access to safe drinking water, increase irrigation capacity, and enhance water management and governance. However, according to the OECD, Afghanistan needs to invest more than 6 percent of its GDP to accommodate flood risks.
- The investment gaps are significant, and the recent Taliban takeover has exacerbated the humanitarian crisis in the country.
- Reaching economic resilience via water resilience in Afghanistan (under the de facto authorities) is solely possible through the

international community. This would require a coordinated and comprehensive approach that addresses the root causes of water insecurity and economic fragility in the country.

- Establishing the Afghanistan Water and Climate Emergency Fund under the UN Special Trust Fund for Afghanistan (STFA), investing in the building and rehabilitation of water infrastructure, and improving public awareness to promote water conservation are recommended pathways until there is a possible handover to a legitimate government.

Introduction

This paper discusses Afghanistan's water resources, changes in the sector before the Taliban takeover, and the pathways to economic resilience via water resilience in the current situation, where the de facto authority is leading the country without any international community recognition. The paper draws a map of recent advances in the water sector, current challenges, and the way forward by recommending the establishment of an Afghanistan Water and Climate Emergency Fund and creating the Afghanistan Water and Climate Emergency Working Group.

Background

Years of political instability and conflict severely affected Afghanistan's economy, resulting in poverty and highly underdeveloped water resources. The COVID-19 pandemic and the Taliban takeover in August 2021 undermined the development gains of the past 20 years and exacerbated conditions further — inducing economic contraction and aggravating food insecurity. According to the World Bank (2022), the GDP has contracted by 20.7 percent in 2021.

The agriculture sector contributes 25 percent to Afghanistan's GDP, employs 40 percent of its labor force, and consumes more than 90 percent of the water, yet cannot provide enough food for Afghanistan's population. Presently 20 million Afghans are acutely food insecure, and more than 6 million are in close to famine-like conditions. Even though 90 percent of household incomes are spent on food, Afghanistan is ranked the highest worldwide for insufficient food consumption rate. Nine of ten households consumed inadequate food, with no changes in the last 12 months (WFP, 2023).

Despite all the rehabilitation efforts and the engagement with the international community for two decades, Afghanistan still has a huge water shortage problem owing to ongoing conflict, mismanagement, poor institutional and human capacity, and climate change. The country has a minimal capacity for water storage of 140 m^3 per capita per year — the lowest in the world. In 2010 the water production per capita in Kabul city was approximately 16 liters per person per day (World Bank, 2010) and has since been unfortunately declining; it is one of the lowest water production figures for any city in the world. For context, that same year water production per capita was 240 liters per person in Dehli, India and 500 for Los Angeles, USA.

Afghanistan, despite having significant water resources, is unable to utilize them effectively. The country's rivers, including the Amu Darya, Helmand, Harirud, and Kabul, offer potential for hydroelectric power generation, irrigation, and other uses. However, due to decades of war and conflict, the existing water infrastructure is severely damaged and inadequate. Moreover, many streams and rivers in Afghanistan flow into desert regions, where they evaporate without replenishing the major river networks. Other rivers and streams only flow seasonally, exacerbating water scarcity and limiting their potential use for agriculture and other purposes.

Groundwater resources are also under immense stress — demand often exceeds supply. In rural Afghanistan, groundwater is largely used for irrigation through Kareezes, mountain springs, and solar-powered wells. As of the end of 2021, three provinces had experienced a drying up of over half (53 percent) of their water points. (UNICEF, 2022). The water scarcity crisis has also had a severe impact on aquifers in the central region, causing reduced water levels and the drying up of various sources such as hand-dug wells, springs, kariz, boreholes, and streams.

Technological innovation in the form of solar-powered deep wells made it possible, especially in southwestern Afghanistan, to change hundreds of thousands of hectares of the desert area into agriculturally productive land, much of it cultivated with opium poppy (Mansfield, 2020). Water tables are also dropping rapidly in metropolitan areas due to over-abstraction for domestic use (USAID, 2021). Groundwater serves as the backup water source during times of surface water scarcity. The loss of these aquifers (or the fossil waters) will be irrecoverable for Afghanistan. All this is happening in a state where very little is known about these aquifers — including how they are recharged and when they might run dry.

Water-related Climate Risks

Climate change exacerbates water sector problems, such as glacial melt, drought, shifting precipitation patterns, and increasing temperatures (Hanasz, 2011). Based on Afghanistan's National Environmental Protection Agency (NEPA) report, temperatures in Afghanistan rose by 1.8 °C between 1950 and 2010, or twice the global average. Afghanistan is one of the most climate-vulnerable countries in the world due to its geography, sensitivity to changing weather patterns, and low coping capacity to deal with climate change (Hakimi and Brown, 2022). In the Global Climate Risk Index 2021, Afghanistan was the sixth most affected country in 2019, with total losses of US$ 548.73 million (Eckstein et al., 2021).

The impact of climate change has caused a decrease in precipitation, which has further aggravated the already strained water resources due to population growth. This has resulted in a severe water scarcity situation in densely populated cities such as Kabul, Kandahar, and Hirat, where 66 percent of the country's urban population resides. Groundwater levels have been declining across Afghanistan, with Kabul witnessing a significant drop from eight meters below land in 2003 to 45 meters in 2021. Moreover, in the first eight months of 2021, over 29,000 people in 13 provinces were affected by natural calamities such as floods, which have added to the problems faced by the people.

The Hindu Kush Mountains in the country are natural storage facilities and sources of freshwater. They accumulate snow during winter and snowmelt and rainfall during spring. These are released as freshwater alongside frozen water from glaciers in the summer, which sustains the vital flow of rivers. This balance of the rivers' systems is being altered, and the people who benefit from these rivers face severe consequences. In Afghanistan, increasing temperatures cause more precipitation in the form of rain instead of snow, resulting in shrinking glaciers and more water when it is not needed. Unfortunately, in the past half-century, larger glaciers in the Pamir and Hindu Kush Mountains have shrunk by over 30 percent, and small glaciers have disappeared completely (WGMS, 2008). These impacts will likely intensify in the coming decades, posing significant challenges to water availability and quality in Afghanistan.

Transboundary Issues

Iran considers the development of agriculture and dams in the upstream area of the Helmand Basin as a significant threat to the environment and water resources, leading to an increase in tension due to water scarcity and environmental degradation. The Helmand River, which contributes 70 percent of the total inflow to the Hamun Lakes and is crucial for farmers in Afghanistan and Iran, has seen reduced downstream flow, leading to the desiccation of the lakes (Akbari and Haghighi, 2022). The desiccation of the lakes has significant environmental and economic impacts on the surrounding population and ecosystem, including air pollution and concerns about water scarcity and environmental degradation. Given that the majority of available water in Afghanistan and Iran is consumed for irrigation, it is essential to address the decreasing inflow of water to the Hamun Lakes.

Water Management Prior to the Taliban, 2021

As one of the vital sectors for Afghanistan, water resources were given priority during the 20 years prior to the Taliban (only after the security organizations). The changes and enhancements in the water sector can be broadly categorized into two main areas: 1) strengthening good water governance and 2) infrastructure development.

Good water governance is essential to achieve water security and provide water services. In order to be able to respond to community needs and deliver services, the Ministry of Energy and Water (MEW) amended the Afghanistan Water Law of 2009, developed 35 legal documents (i.e., regulations), policies and strategies, and implemented institutional changes at the ministry as well as at the river basin level. The government and international community, via different platforms (e.g., training, workshops, and graduate scholarships abroad) trained a large number of water resources engineers and specialists who were able (to some extent) to fill the human capacity gap in managing water resources.

The previous administration's budgetary constraints and limited spending power were one of the major obstacles in dealing with water resources and climate change. Between 2013 and 2015, the government spent over US$ 100 million annually on climate change through its development budget; nevertheless, this amount was insufficient compared to the US$ 662 million needed per year (Islamic Republic of Afghanistan, 2015)

Related to infrastructure development, a large amount of focus and resources were given to building or rehabilitating large and medium-scale dams in Afghanistan (e.g., the Salma Dam, Kamal Khan Dam, Kajaki Dam Second Phase, Bakhshabad Dam, Dahla Dam, Shorabak Dam, Pashdan Dam, Shah-o-Aros Dam, Tori Dam, Shahtoot Dam, Machalgho Dam, Sultan Dam, and Palato Dam). Some of these dams were completed, and the remaining were under construction. Additionally, 47 more dams were surveyed, designed, and either contracted for construction or under the procurement process. In addition to these large and medium-scale dams, a program of around 4,500 check dams was also under implementation.

There were also irrigation projects of different scales, ranging from the Shahi Canal (serving 22,000 hectares of irrigable land) up to the Khoshtepa Canal in Northern Afghanistan (serving 500,000 hectares of irrigable land). Further, hundreds of main canals were engineered, and around 3,000 irrigation schemes were rehabilitated.

The previous administration worked with the international community to install 183 hydrometeorological and hydrogeological stations for data collection. Four early warning system pilot stations were set up to lessen the negative consequences of hydrometeorological risks on vulnerable communities.

Afghanistan's economic resilience is directly tied to water resilience. With all the advances, Afghanistan's water sector still needs more systematic efforts to utilize its water resources. Previous shortcomings were not only because of mismanagement and climate change; the water sector also struggled with financial limitations, data unavailability, and the involvement of many stakeholder ministries/agencies with very poor coordination. Above all, security was a massive problem for the water management projects. According to former Water Minister Mr. Takal, "Only in Machalgho Dam we had more than 130 security guards martyred, and hundreds wounded." This was done by the Taliban to obstruct government operations. More importantly, the security issue was from the neighboring countries because of the transboundary nature of Afghanistan's water.

Role of Official Development Assistance Financing in Water Infrastructure Development

The advances made in the last two decades were only possible with Official Development Assistance (ODA) for the water sector from various international organizations and donor countries. The water sector in Afghanistan is vital for its economic and social development, and ODA played an integral role in addressing water challenges. The key contributors that have provided ODA for the water sector in Afghanistan are the World Bank, Asian Development Bank (ADB), European Union, United States Agency for International Development (USAID), and UN agencies, particularly United Nations Development Programme (UNDP).

The assistance provided by these institutions was used for several purposes, such as the development of water infrastructure, rehabilitation of existing systems, and improving water governance and capacity building. These projects included the construction and rehabilitation of irrigation systems, on-farm water management, installation of water supply networks, rehabilitation of hydropower plants, and support for water resource management programs.

The ODA for the water sector in Afghanistan over the last 20 years has been notable; however, the water sector still needs a lot more. According to the World Bank, as of 2021, the total amount of funds allocated to the water sector in Afghanistan since 2002 was over US$ 4 billion. These funds have been used to support various programs aimed at improving access to safe drinking water, increasing irrigation capacity, and enhancing water management and governance in the country.

According to the OECD (2021), Afghanistan needs to invest nearly 3 percent of its GDP (around US$ 1 billion) in its water supply and sanitation infrastructure to achieve universal access to safely managed water supply and sanitation services. Not only are the investment gaps enormous compared to what is available in the country to invest in the water sector, but the Taliban takeover has led to a humanitarian crisis with millions of people in need of necessities such as food, water, and healthcare. In the meantime, to accommodate for flood risks, Afghanistan needs to invest more than 6 percent of its GDP in a business-as-usual scenario.

What is Next? Water Resilience towards Economic Resilience Mainstreamed by the International Community

Afghanistan's water resources are under enormous stress from the impacts of climate change, population growth, mismanagement of the sector in the last four decades because of continuous conflict and insecurity, financial limitations, insufficient technical capacity, data unavailability, and other drivers. Currently, Afghanistan is in a highly vulnerable situation confronting the second drought in four years — the worst of its kind in 27 years. The country has the highest number of people in emergency food insecurity worldwide (UNDP, 2022).

The following section will discuss the pathways to economic resilience via water resilience in the current situation of Afghanistan under the Taliban. Knowing that the international community has not yet recognized the de facto authorities in Afghanistan, working with them is not an option; therefore, this paper's recommendations rely on the current international organizations operating in Afghanistan, such as the UN agencies, World Bank, ADB, and some national and international NGOs.

Here are a few reassuring signs that could allow Afghanistan to take the first steps toward water resilience. First, the de facto authorities and the international community do not have political, religious, or cultural disagreements regarding addressing the current water and climate crisis. Secondly, international NGOs and United Nations offices are actively operating in the country. Examples include UNDP, UN-FAO, WFP, and others.

Reaching economic resilience via water resilience in Afghanistan (under the de facto authorities) is solely possible through the international community. This would require a coordinated and comprehensive approach that addresses the root causes of water insecurity and economic fragility in the country. All partners should work together, including bilateral donors who are already providing humanitarian aid (such as the World Bank, ADB, USAID, DFID, etc.), multilateral donors such as the climate finance institutions (e.g., GEF, GCF, and AF), and partners physically present in Afghanistan like the United Nations Offices (especially UNDP who has a wealth of experience in water resources and climate change projects), national and international NGOs, and local communities (e.g., Community Development Councils). All the major players must step up and participate in addressing the current water and climate problems. This paper recommends that a few key organizations, especially those in Afghanistan, including UNDP, UN-FAO, and the World Bank, establish the Afghanistan Water and Climate Emergency Working Group.

A good financial setup is of utmost importance in managing water resources and climate change. Thus, establishing the Afghanistan Water and Climate Emergency Fund is one way to give proper attention to climate change and water resources projects. Establishing the Fund will centralize and ring-fence the finance within a dedicated setup, allowing for coherent investment and improving the confidence of bilateral and multilateral donors. Furthermore, it will avoid fragmentation and promote collaborative planning, coordination, and prioritization of water resources and climate change. It is worth mentioning that the former government approved the formation of a national environmental and climate change fund with NEPA being the leading agency working on its establishment. Back then, the idea was also to give the right platform for financing the climate change agenda through grants (i.e., bi- and multilateral donors such as the GCF, GEF, AF, WB, ADB, EU, and others) and private investments.

Because of the political limitations with the de facto authorities, the faster path could be establishing the Afghanistan Water and Climate Emergency Fund as a separate wing under the Special Trust Fund for Afghanistan (STFA) by the United Nations. Established in 2021, the STFA is an inter-agency structure and UN-Multi-Partner trust fund to assist UN joint programming in providing basic human needs in Afghanistan. In its mandate, STFA has already been investing in climate change projects under the "Protecting Farm-Based Livelihood from Natural Disaster" pillar of the ABADEI Project; however, as stated before, in order to give the proper focus and attention to the water and climate crisis in Afghanistan, a separate, dedicated financial setup is necessary.

To first get Afghanistan out of this emergency and then reach economic resilience in the medium and long term(s), enhancing water resilience is a crucial factor. Here are some possible actions that could be pursued to enhance economic resilience via water resilience under the de facto authorities:

1. **Create the Afghanistan Water and Climate Emergency Working Group**, comprising key partners such as the UNDP, UN-FAO, World Bank, and others currently operating in Afghanistan. Moreover, establish the **Afghanistan Water and Climate Emergency Fund** under the UN Special Trust Fund for Afghanistan (STFA). This will centralize and ring-fence the finance within a dedicated setup, giving proper focus and attention to the country's water and climate change emergency and optimistically resulting in attracting funds from bilateral as well as multilateral donors.
2. With the current situation in mind, **provide humanitarian assistance**. Currently, in Afghanistan humanitarian assistance is critical for meeting the basic needs of vulnerable populations, such as food, water, and health. The international community could provide humanitarian assistance to address the immediate water and economic needs of Afghan communities, particularly those affected by conflict, displacement, and natural disasters like recent floods and droughts.
3. **Promote local ownership and participation**. Water resilience and economic resilience are best achieved when local communities and stakeholders are engaged and empowered to co-create and co-implement solutions that address their specific needs and priorities. The international partners could

prioritize community-led water management and governance approaches, such as participatory water management committees, and support their capacity-building and resource mobilization efforts. Furthermore, the working group could invest in institutional development and enhancing human resources capacity, as most water experts/specialists have been fired by the de facto authorities or left the country because of insecurities.

4. Through the setups mentioned above (i.e., the Working Group and the Fund), partners should **invest in the building and rehabilitation of water infrastructure**, such as check dams, irrigation systems, and wells, to increase water availability for domestic, agriculture, and industrial use. This will also reduce the impact of climate change, improve access to safe drinking water and sanitation facilities, increase agriculture productivity, and improve food security. Afghanistan's water infrastructure needs rehabilitation and expansion to meet the growing water demand and enhance water security. Rehabilitated irrigation systems have proven to help farmers by avoiding water shortages and allowing them to switch from low-earning to high-earning crops and generate higher revenues.
5. **Improve public awareness and promote water conservation and efficiency** to avoid over-exploitation of water resources, particularly groundwater. Water conservation and efficiency measures can help to reduce water demand and increase productivity, particularly in water-stressed areas. Long-term investments can be made in water-saving technologies like drip and sprinkler irrigation, rainwater harvesting, and water reuse to improve water use efficiency and reduce the stress on water resources.
6. **Once a legitimate government is in place, hand over** the Afghanistan Water and Climate Emergency Fund and the Emergency Working Group to the Ministry of Energy and Water (MEW), the National Environmental Protection Agency (NEPA), and the Ministry of Finance (MoF).

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Increasing Water Resilience with Jordan's National Water Master Plan

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Key Messages

- Jordan's economic and social resilience, as well as food security, are challenged by dwindling conventional water resources, population growth, and climate change. The World Bank has estimated up to a 6 percent GDP loss by 2050 due to climate change impacts on water resources.
- Jordan's water supply comes from rivers (32 percent), groundwater from underground aquifers (53 percent), and treated wastewater (15 percent). However, groundwater depletion is occurring at a rate three times faster than the recharge rate, which could compromise much of the country's infrastructure in the next few years.
- The Third National Water Master Plan (NWMP-3) has enabled evidence-based investment decisions by facilitating the integration of climate change effects into its strategic planning. Its detailed water supply and demand modeling at the municipal level accounts for the diminishing availability of underground water, which was previously presumed to be steady and stable.
- Reusing treated wastewater is an opportunity for Jordan to increase economic resilience. In 2020, treated wastewater contributed by 15 percent to the total water resources, with 91 percent being reused in the agricultural sector.
- The lack of coordination among decision-makers responsible for

water supply, wastewater treatment, and treated wastewater reuse is a major obstacle in effective water resources management.

Introduction

Jordan is an upper middle-income country, as classified by the World Bank. Like all economies in the region, the Jordanian economy has been significantly strained by the COVID-19 shock as well as the Ukrainian War. Nevertheless, its recovery is transitioning compared to the previous national crisis. In 2021, the economy experienced a positive recovery compared to the contraction seen in 2020, where the real GDP grew by 2.2 percent. Positive projections by the World Bank and IMF proceed towards economic growth by around 2.4 percent up to 2024. Services are the primary contributors to the GDP by 60 percent. Industry contributes by 25 percent and agriculture 5 percent.

Jordan is facing significant challenges in terms of its water resources, which are compounded by the effects of climate change, including more frequent and severe droughts and changes in precipitation patterns that could reduce the amount of water available for use. In terms of water scarcity, Jordan ranks fifth globally amongst the extremely high baseline of water stressed countries (World Resources Institute, 2019). Renewable water supply covers 93 m^3 per capita annually, 400 m^3 below the absolute water scarcity threshold (World Bank Group, 2022). Jordanians, residing in one of the most arid regions globally, are familiar with a weekly household water supply of only 36 hours (Zraick, 2022). Jordan's water supply comes from various sources. Water from rivers such as the Jordan and Yarmouk contributes 32 percent of the supply. Groundwater from underground aquifers provides 53 percent and treated wastewater accounts for 15 percent.

In addition to the impacts of climate change, Jordan is also facing economic and social challenges that make it difficult to build resilience and adapt to water scarcity. The country has a growing population and limited natural resources, which puts a strain on its economy and social systems. For example, groundwater overexploitation in Jordan started in the late 1980s, mainly for agricultural production (Margane et al., 2002). Recent studies using remote sensing show that agricultural water consumption still constitutes around 60 percent of overall water consumption (Al Bakri, 2021; MWI, 2016). This is largely due to the growing number of illegal wells and is compounded by the utilization of water in industry and manufacturing — predominantly for the chemicals and packaging sector.

Current overuse of groundwater is around three times the rate of actual groundwater recharge. As a result, groundwater levels are declining more than 5 m/year, leading to a continuously shrinking supply of groundwater. Therefore, many of the wells currently being exploited will be dry in the future. In turn, water scarcity further drives up energy demand and costs through the need for additional water pumping from greater depths. By 2040, an average 100 m higher pumping lift, compared to 2018, will be required to extract groundwater. This means that pumping water will require approximately 40 percent more energy over the same timespan, impacting all economic sectors through rising energy demands.

The growing pressure on Jordan's water security is attributed to several factors that contributed to increased consumption, including a two-fold increase in population to 11 million from five million over the past decade, compounded by the influx of refugees from war-torn neighboring regions. The temperature rise of 1.5–2 °C during the last two decades and the projected increase of 1.5–3.75 °C between 2080–2099 are crucial factors that highlight the significant contribution of climate change, according to UNICEF (2022). This increase has led to Jordan's placement of 73 out of 182 countries in the ND GAIN index for climate vulnerability (ND-GAIN, 2023).

Based on regional climate model results, climate change is estimated to lead to a decrease in groundwater and surface water availability by approximately 15 percent each through 2040. This decline would result in a countrywide decrease in long-term groundwater recharge from 280 MCM/yr to approximately 240 MCM/yr by 2040. Similarly, long-term surface water runoff would decrease from around 400 MCM/yr to around 340 MCM/yr over the same period (2018–2040). As a result, the internal long-term conventional water resources availability will decrease from current levels of 65 m^3/ca/yr to 46 m^3/ca/yr in 2040. Changes in water quality are also expected, with increased salinity in the aquifers due to lower groundwater recharge and higher groundwater use for agriculture, leading to higher irrigation return flows. This will increase the presence of elements like molybdenum, nickel, arsenic, selenium, and radioactivity (radium), which are detrimental to human consumption and require higher intensities of water treatment and associated costs in the future.

Jordan faces a dual challenge of water scarcity and the mounting impact of extreme weather events, such as heavy rainfall and flash floods. The heightened intensity or frequency of these events can lead to agricultural losses and adversely impact the tourism sector, particularly in the southern region of the country. The resulting damage to infrastructure and the economy is significant. However, these events also offer an opportunity to boost groundwater recharge, which has been largely overlooked in Jordan. Groundwater recharge can be achieved by allowing excess rainwater to infiltrate the ground, replenishing the groundwater aquifers that are a critical source of water for the country. In Jordan, there is a need for integrated water resources management that considers both surface water and groundwater resources, and links between them. Given the increasing frequency of extreme weather events, it is crucial to explore ways to capture and store rainwater in a way that facilitates groundwater recharge.

Creating a National Water Master Plan to Ensure Resilience

Previous planning assumed a constant or even increased availability of renewable water resources, although it was known that groundwater resources have limited availability and are already highly overexploited, while surface water resources are nearly fully exploited. Within the framework of the Management of Water Resources Project, GIZ is preparing together with its three water sector partners — the Ministry of Water and Irrigation (MWI), the Water Authority of Jordan (WAJ), and the Jordan Valley Authority (JVA) — the Third National Water Master Plan (NWMP-3). The primary objective of this plan is to incorporate all the critical factors that affect water utilization in Jordan, including future projections, and their impact on water supply security and overall resilience. It is essential to recognize the direct correlation between water scarcity and economic growth.

The NWMP-3 plan has made it possible for Jordan to integrate climate change impacts into its strategic planning for the first time. To accomplish this, a crucial step was to assess and analyze water supply and demand at the municipal level. This analysis has enabled the country to make predictions about the future and is currently informing its strategic investments in the water sector.

In its Rapid Assessment (GIZ & MWI, 2020) and the Water Resources Volume B of the NWMP-3 (GIZ & MWI, 2021), it is predicted that the production for domestic water supply from renewable groundwater resources (both governmental and private) will decline to 29 percent of the 2018 amount. The existing supply gap (65 percent) can only be closed by massively investing into desalination technology. For the first time, the NWMP-3 has succeeded in integrating the impacts of climate change (GeoTools, 2021) and the decline of conventional water resource exploitation into the water sector's strategic planning. The decline of conventional water resources availability and exploitability means that additional water resources must be made available to ensure municipal water supply security. This includes non-conventional resources — predominantly desalination of sea and brackish water — to suffice the demands in 2040. To this end, the Aqaba Amman Water Desalination and Conveyance (AAWDC) project is being developed, which is set to provide an impressive 300 MCM/yr, making it the largest seawater desalination facility in the world.

Economic water demand is the amount of water a household would want to consume at a given water price or tariff rate, depending on that household's socio-economic characteristics. Under a system with supply interruptions, water demand quantities can exceed actual consumption. With the continuing rise in income levels, it is expected that the per-capita water demands in all governorates of Jordan will gradually increase over time, with projections of a 15 percent increase over 2020 by 2040 — on top of demand growth from the expanding population.

An analysis of household water demands was conducted using a coupled hydro-economic multi-agent model. The water demand estimate was detailed per municipality, and has indicated that households in different governorates would expand their current consumption to a varying degree under a supply system with uninterrupted access to piped water. Households in Amman governorate, for example, would currently be expected to expand their consumption by 12 percent beyond 2018 levels, whereas most other governorates would see a greater increase, based on lower current supply quantities or higher demands.

Water Allocation Gaps (Water Balance)

The total municipal water demand (supply requirements) was estimated at 621 MCM for all governorates in 2018. The projected demand will increase by 28 percent reaching 798 MCM in 2040. This increase is attributed to population growth only, if non-revenue water (NRW) will remain at the current level of 53.3 percent.

Water supply of 476.6 MCM in 2018 has satisfied 77 percent of the required demand, excluding water use for irrigation through the network (around 5.5 MCM). However, the gap between the remaining water production and the required demand is widening due to an increase in demand and the expected substantial decrease of production from conventional water resources. By

2040, the available production of water resources will satisfy only 36 percent of the required demand as the remaining production will drop to around 279.6 MCM.

In 2018, only 460.5 MCM could be produced from the existing governmental water resources. An additional 332.6 MCM is required to meet the demand of 2025, and the deficit will increase to 518 MCM by 2040. This gap urgently needs to be addressed through planning of projects for water augmentation.

Although cost-intensive water-loss reduction programs have been implemented over the course of the past three decades, they have failed to achieve their aim. NRW has constantly remained at almost the same level. However, in all cases the impact of reduction in NRW compared with the current situation revealed 4 percent of recovery for demand coverage. This would amount to 89 MCM in water savings if successfully implemented — a challenge considering the continuous expansion of the network and new possibilities for losses. It is also important to note that the calculation of NRW only considers the supply infrastructure and not the abstraction side.

Wastewater Treatment, Reuse, and Water Supply (WTR): An Opportunity for Enhanced Resilience

Climate induced effects such as extreme heat and water scarcity as well as saltwater intrusion are damaging Jordan´s water and wastewater infrastructure, affecting basic service delivery and leading to low energy efficiency. One opportunity to strengthen water resilience in Jordan is to reuse treated wastewater, thereby decreasing the pressure on Jordan's freshwater resources. A project entitled Wastewater Treatment, Reuse, and Water Supply (WTR) helps to improve the performance of selected water sector institutions in Jordan. This includes WAJ and three water utilities: Miyahuna Water Company (MWC), Yarmouk Water Company (YWC), and Aqaba Water Company (AWC).

The main goals of the project are to enhance the availability of treated wastewater of high quality for restricted agricultural and industrial standards. One aim of the WTR project is that 95 percent of treated wastewater in nine wastewater treatment plants are following the Jordanian quality standard known as JS 893/2006. Another target is to increase operational optimization of the wastewater treatment plants (WWTPs) and hence reduce electricity consumption by 15 percent. Further goals include improving the technical and human capacities in the water and wastewater sector, optimizing the use of water resources in Jordan, and increasing the quality and quantity of treated wastewater from the 33 WWTPs all over Jordan.

Jordan faces financial challenges in the water sector. The transmission and treatment of water as well as wastewater is connected to high costs due to the quality of the raw water, which often must be treated. Due to the topographical conditions of the country, the water must be pumped up to the necessary heights using a large amount of energy. Therefore, it is economically important that every cubic meter of water is preserved, which is why Jordan aims to increase the proportion of the population connected to a sewer system from 69 percent (2020) to 80 percent by 2030 (MWI, 2016). Also, current water tariffs are too low for the sustainable operation of water utilities. Therefore, the WTR project promotes efficient and effective use of scarce resources in the sector. In addition, heavy rainfall events lead to flooding in winter, which can cause blockage by debris or silting in sewage treatment plants or overflowing of the plants. The absence of rain, on the other hand, results in increased concentrations of pollutants, making biological treatment within the plant less effective.

While water scarcity leads to higher water and food costs, higher water availability would instead lead to lower prices for food and water. Increased opportunities for small-scale farmers can be created, and reducing prices for water for domestic use and irrigation can help to alleviate poverty. As pointed out before, the agricultural sector is most vulnerable to changes in water availability. Around 91 percent of the treated wastewater is reused in the agricultural sector and in 2020, treated wastewater made up 15 percent of the total water resources. For example, in the northern governorates, a reuse pipeline system was implemented to substitute 40 percent of the irrigation water with treated wastewater. The treated wastewater is transported from the Wadi Arab WWTP through a pipeline to the Wadi Arab dam and mixed with freshwater. Eventually, the water is used for irrigation of restricted agricultural sectors in the Jordan Valley and freshwater demand is thus reduced. Further examples for the use of treated wastewater are irrigated golf courses for tourism in Aqaba or the irrigation of urban green areas in the city of Amman.

The use of treated wastewater has an economic importance in several sectors as it supports securing employment, especially in the agricultural and the water sector. Currently, organizational and technical capacities are not sufficient to ensure proper operation of complex WWTPs in Jordan. WTR therefore supports capacity development of utility staff and an improved management of the WWTPs to enhance operational effectiveness, efficiency, and sustainability. An approach known as Technical Sustainable Management (TSM) was introduced, and key performance indicators (KPIs) were developed to enhance wastewater management. The aim of the TSM approach is operational improvement and sustainability. It consists of repeated certification according to defined quality criteria and evidence-based recommendations by the supervisory body to improve wastewater management. So far, nine WWTPs have been successfully certified. Continuous surveys of key technical and financial performance indicators of the wastewater treatment plants show a gradual reduction in energy consumption as well as an increasing improvement in the quality of the treated wastewater. The WTR project also promotes the conducting of Training Needs Analyses (TNAs) that allow targeted capacity development for management and operating staff. As a result, plant operations are improved, and the skills of individual employees are strengthened, providing enhanced career opportunities.

Policy Interventions As Proposed by NWMP-3

The Third National Water Master Plan (NWMP-3) for Jordan proposes a range of policy interventions to improve water resource allocation and management. The following proposed interventions enable the national governments to prepare for climate change and plan for it to streamline resilience.

1. **Improve the Water Resources Allocation Plan through national level planning coordination.** To enable economic resilience, an improved water resources allocation

plan is necessary in Jordan. This plan should clearly allocate the resource to different uses based on comprehensive data and with major coordination among related parties. Currently, allocation and investment planning are done without such coordination and data, leaving some parties behind. Achieving this requires a continuous negotiation process among all related parties, with transparency and information sharing being crucial. However, transparency and information sharing remain significant obstacles in many developing countries, particularly in Jordan.

2. **Establish a Water Resources Allocation Committee.** A Water Resources Allocation Committee is needed, which brings together all stakeholders, meets on a monthly basis, and determines the required allocation of water for all sectors. However, severe obstacles at the management level must be overcome, as decision-makers often prioritize specific interests and neglect water resources management issues. This often results in a lack of understanding of the reasons behind a decline in water resources, which is sometimes ignored for political reasons. Coordination among managers responsible for projects of water supply, wastewater collection and treatment, and treated wastewater reuse are still an exception rather than the norm.

   When conditions were favorable, the project attempted to address these challenges by establishing a Joint Planning Committee. The committee's purpose was to openly discuss proposed projects and conditions, question the feasibility and usefulness of such projects, and identify any inconsistencies in data or assumptions. For instance, it brought groundwater vulnerability criteria into consideration while justifying sanitation projects (Margane & Steinel, 2011). However, this effort faced challenges due to the unfavorable conditions brought about by COVID-19 and the beginning of water sector reform efforts, which led to less coordination among the various units competing over funding.

3. **Assess and incorporate the water costs from different supply channels and price them accordingly.** Economic resilience considers the cost of municipal, industrial, and agricultural water uses. Drastic actions, as proposed by the NWMP-3, are needed to improve economic resilience when facing drastic changes in conventional water resources availability and exploitation in Jordan.

   Appropriately considering the cost of water is important for finding the optimal solutions; however, operation and maintenance costs of water supply systems, wastewater collection and treatment systems, desalinated water, and treated wastewater reuse systems are currently not assessed by WAJ or by the water utilities. In addition, the cost of groundwater extraction through wellfields is also not considered (QADI et al., 2018). Hence, there is a need for policy change and prioritizing the use of cost as the primary criterion to determine which source of water should be utilized in a particular region.

4. **Incorporate treated wastewater as an alternative water resource**

for industrial water consumption. Industrial development has increased in Jordan over the past decade, with industrial activities contributing 28 percent to GDP in 2018 (World Bank, 2022). The major industries are mining and manufacturing. Phosphate and potash mining, cement production, petroleum refining, and fertilizer production utilize the biggest share of industrial water. The mining sector is the main industrial water consumer (90 percent) and generates around 8 percent of national GDP. It is thus highly relevant that the mining sector receives an adequate and stable amount of water.

Alternative water resources availability for the commercial and industrial sectors currently impedes economic growth. The challenge is that in most locations there is no alternative to the use of groundwater. Industrial demand currently is around 40 MCM/yr, or 3 percent of overall water use. This amount is projected to increase to approximately 72 MCM/yr by 2040 (GIZ and MWI, 2022). Thus far, industrial water supply depends mostly on groundwater (approximately two thirds); however, in many industrial processes, treated wastewater reuse could be an option.

The coordination between MWI and the Ministry of Industry or other related entities in the commercial and industrial sectors is weak and there is no agreed procedure for requests and water resources allocation. This also means no planning security for companies. The MWR project is in the process of defining where treated wastewater could be reused from which WWTP source to strengthen this coordination. Since groundwater use shall be prioritized for municipal use, many industries are moving water-intense activities into Aqaba with plans to use desalinated seawater.

5. **Incentivize farmers to use wastewater and create a monitoring system for agricultural consumption.** Agriculture has increasingly depended on treated wastewater reuse (Oweis, 2021). Although there is a sufficiently expanded distribution network for reuse, some farmers in the northern and central parts of the Jordan Valley still prefer not to reuse treated wastewater. In the highlands, as of 2020 there were 370 signed agreements for treated wastewater reuse around the existing WWTPs. However, there is no related monitoring.

   In addition, the lack of coordination among related parties has resulted in weak implementation of treated wastewater reuse by farmers. To address this issue, treated wastewater reuse can be implemented near the effluent discharge points of existing wastewater treatment plants, where it does not have any impact on relevant groundwater or surface water resources. The project is actively seeking to improve actual reuse and related infrastructure in areas where it is possible to increase reuse.

6. **Make evidence-based decisions for water sector investments.** The integration of Water Evaluation and Planning (WEAP) analysis and similar scenarios in the decision-making process is needed for resources management and investments planning. It is important that

investment decisions rely on proper monitoring and analysis of water resources data, considering climate change impacts and the decline of conventional resource availability and exploitability in the water supply strategy and project planning. Data collection and analysis is essential, along with maintaining a quality database. Having these strong data will allow for the creation of more evidence-based policies. Data collection should cover a range of factors: long-term availability, exploitability, quality, protection, feasibility of raw water treatment, climate change impacts, actual uses, demand prognosis, costs of water, allocation planning, joint project and capital investment planning, and many other aspects.

Conclusions

Jordan is facing a complex challenge in managing its water resources given the country's population growth, climate change, and the dwindling availability of conventional water resources. Jordan's water scarcity is exacerbated by the ongoing Syrian refugee crisis, which has added pressure to the already limited water resources of the country. The National Water Master Plan (NWMP-3) has been a significant milestone for Jordan, as it allowed for the identification of the demand gap for water supply at the municipal level, enabling future projections and predictions for water supply and demand.

However, the demand for water in Jordan is expected to rise significantly in the coming years, and the availability of conventional water resources is projected to decrease. Therefore, to address the existing supply gap, massive investments in desalination technology such as the Aqaba Amman Water Desalination and Conveyance (AAWDC) project are necessary. Moreover, Jordan needs to adopt a holistic approach to water resource management that includes policy interventions, efficient use of available water resources, and the incorporation of new technologies.

The successful implementation of policy interventions outlined in NWMP-3 is crucial to ensuring Jordan's economic resilience in the future. The government and stakeholders must work together to coordinate and share information, prioritize cost as the primary criterion for determining water source utilization in specific regions, and incentivize the use of treated wastewater for agriculture. This strategy will not only reduce the demand for conventional water resources but will also improve the economic viability of the agricultural sector.

In addition to these policy interventions, the development of a comprehensive water resources allocation plan and a water resources allocation committee is essential for effective policy implementation. It is crucial to incorporate water costs from different supply channels and plan for water reuse, especially for industrial and agricultural demand. Furthermore, creating incentive programs for farmers to use treated wastewater for irrigation and integrating evidence-based decision-making into water sector investments using tools like WEAP analysis and scenarios can help promote a resilient water system and foster economic sustainability in Jordan.

Overall, a sustainable and resilient water management system is critical for Jordan's economic and social development. Effective policy interventions, efficient water use, and the incorporation of new technologies are essential components of this system. By adopting a holistic approach to water resource management, Jordan can mitigate the impacts of water scarcity, ensure economic resilience, and provide sustainable access to water for its population.

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Water Resilience for Economic Resilience in the Netherlands: From Floods to Drought

by Karianne de Bruin[1]

[1] Deltares

Key Messages

- The Netherlands uses a comprehensive approach to protect against flooding, combining laws, land-use planning, and infrastructure. Economic incentives and innovative building methods help reduce flood risks through mechanisms such as green bonds aimed at enhancing climate resilience.
- The Netherlands' challenge is to become resilient to both too much and too little water. Since 2003, western Europe, including the Netherlands, has faced recurring intense droughts, with significant consequences in 2022. Understanding the environmental and economic impacts of droughts in the context of climate change and upstream developments is key.
- As the Netherlands grapples with the emerging issue of droughts alongside traditional concerns of flooding, the country is rethinking its resilience strategy at local levels. While complete protection from both threats is unattainable, new tools and balanced investments aim

to maintain a high standard of living and attract investment amid an evolving climate.

- The Delta Programme's successful approach to flood risk management offers a blueprint for tackling droughts, emphasizing urgency, inclusive participation, idea incubation, and consensus-building to inform long-term adaptation strategies.
- Collaboration is essential in terms of upstream developments and planned investments and to learn from other regions across the world that have been dealing with too little water for much longer.

Introduction

For more than a millennium, the Netherlands has experienced regularly extreme inundation events, most often from storms from the North Sea and high river levels from inland, upstream precipitation. Many regions accounted for this in their implicit development strategies to "reclaim" land from the sea for farms and cities, building dykes to secure land from high waters, and extensive, constant pumping to move water away from low elevations. Nearly 60 percent of the Netherlands' area is susceptible to large-scale coastal and river flooding. About one-quarter is below present mean sea level, making flood risk management and adaptation to sea-level rise essential for its existence.

National economic planning was shaped by the need to secure property and life from the threat of flooding. This was a side effect of the strategy of economic growth through, in part, increasing the area of the Netherlands through the conversion of near-shore areas into dry land. Governance, land-use planning, and infrastructure operations and investment were tightly integrated to reduce flood risks. Many of these approaches became integrated into a national water- (and flood-) centric Delta Commission in 1953 after a catastrophic flood event in the southern part of the country. Much of the language around these issues described "fighting" water from rivers and the sea. A legal framework was established, including norms for flood protection. Rijkswaterstaat, regional water boards, and an expert community worked together to maintain the framework of protecting the Dutch delta against flooding. However, as pointed out by Van Buuren (2019) who assessed the Dutch Delta approach, two "near-miss" riverine flooding events in 1993 and 1995 showed that "past success could not be allowed to breed complacency." This resulted in the implementation of the Flood Protection Act and the establishment of the "Room for the Rivers" program to enhance the discharge capacity of the rivers.

The twenty-first century has seen quite different drivers and trends emerge, with the threat of climate change taking a more dominant role. A second Delta Commission was convened in 2007, which initially focused on higher flood risks to ensure long-term flood resilience for the Netherlands. The second Commission targeted governance reform, more flexible approaches to planning to cope with uncertainties in the timing of growing flood risks, sea-level rise, and the use of nature-based solutions integrated within traditional gray infrastructure systems. Economic incentive systems promoted mechanisms to reduce flood risks even with more intense flood events, such as promoting local climate adaptive design through subsidies for green roofs, and stimulating innovations for floating domestic and commercial constructions.

National finance institutions took a leading role. For example, the National Waterboard Bank (NWB) issued the largest green bond in European history in 2019 for €5 billion, which funded projects related to: climate change mitigation (in the form of waterway management), climate change adaptation, investments in climate-resilient growth (e.g., flood protection and other flood defenses, and pumping stations), and biodiversity projects related to water (NWB Bank, 2019). The NWB is a publicly owned financial institution that only provides funding to water authorities and local governments. Proceeds from green bonds are allocated to a selected pool of loans that promote the transition to low-carbon and/or climate resilient growth through financing of adaptation measures as determined by the water authorities, according to their mandate as defined by the Dutch Water Act. Climate resilience is at the heart of the water authorities' activities (CICERO Shades of Green, 2022).

From Floods to Drought

Beginning in 2003, western Europe began to experience a series of intense droughts that have continued into 2023. In the Netherlands, four of the last five years were exceptionally dry. In 2022 spring and summer were characterized by a combination of prolonged periods with little rain and large evaporation due to the sunny warm weather. This meant that not only the supply of water was lagging behind due to rainfall, but that also the supply of river water was low, with significant consequences. Due to the low water levels in the rivers, shipping became more difficult and transport between Rotterdam and the German hinterland was limited.

The intake of freshwater for groundwater level management and flushing of the polders to combat salinization was also limited. Bans on water exclusion meant that crops could not be supplied with sufficient water. The bans on water exclusion by the agricultural sector were determined based on the "displacement series" as defined in the Water Act. The series indicates how the distribution of freshwater is prioritized across different sectors. For the agricultural sector this often means that in parts of the country there is a ban on using fresh water to irrigate crops. Yields for arable farming were ultimately not severely impacted by the 2022 drought, and due to higher prices, there was an improvement in income for arable farmers.

Other activities were also impacted. Due to the high water temperatures, the efficiency of energy production decreased. Water quality was significantly reduced, leading to problems such as the explosive growth of blue-green algae and botulism, restricting the ability for citizens to swim in open water due to possible health impacts.

Understanding the Economic Impact of Drought

Incidental drought has positive economic effects for some sectors such as shipping and agriculture due to (temporarily) higher prices for products and services. However, prolonged dry conditions also have many indirect consequences everywhere from urban areas to peat meadows to nature reserves.

The consequences can be large for natural systems. The Netherlands has many protected groundwater-dependent ecosystems at risk from droughts. Elsewhere, peat meadow areas face irreversible oxidation resulting in CO_2 emissions.

Infrastructure is also impacted. Reductions in groundwater can lead to damage to foundations (pole rot) and buildings or other structures (uneven settlement) for which repair costs are high. Drying out of peat dykes and cracks in dykes with a clay layer can further reduce the stability of flood defenses, meaning that prolonged drought thus increases the risk of flooding. In the Netherlands, between 750,000 and 1,000,000 properties have a wooden pile foundation or a foundation on steel. These buildings are sensitive to drought. The expectation is that the damage to these buildings may increase until 2050 up to €60 billion due to pole rot, low groundwater levels, and increasing drought (KCAF, 2021).

The impacts of the 2018 drought in the Netherlands have been assessed and quantified by researchers. Ecorys (2019) estimated the overall economic effect of the 2018 drought at €450–2080 million. Mens et al. (2022) estimated economic consequences of future droughts following a worst-case Delta Scenario 2050 (Stoom) for the economy, where economic growth, strong population growth, and strong and rapid climate change converge. The scenarios provide qualitative and quantitative data on the climate, water systems, water consumption, and the use of land. Based on the model simulations, the current drought risk in the Netherlands is estimated at €372 million per year and may increase to €611 million through 2050.

Adapting to Water Shortages

Adapting to water shortages is the main challenge for the Netherlands, and much more complex than adapting to high water levels. Reforms are necessary on numerous fronts. Long-term structural adjustments will be needed to maintain the navigability of the major rivers. Space must be found to develop large-scale water storage. Sustainable groundwater management plays an important role as well.

Adapting to saltier and drier conditions requires commitment from the entire water chain — from both the supply and demand side. Possible options include growing other crops, infrastructure that is much more resistant to corrosion, and increasing water retention in both surface water and groundwater.

The Delta Programme’s approach to flood risk can serve as a good example for the implementation of structural reforms to deal with droughts. As pointed out by Van Buuren (2019), the second Delta Programme reinvented its policy approach to implement structural reforms. Important mechanisms in the context of adapting to water shortages included: 1) emphasizing the urgency of adapting to water shortages, 2) facilitating the participation of a broad range of actors, 3) creating a seedbed for promising ideas, and 4) achieving joint fact-finding to establish consensus and build upon existing institutions (Van Buuren, 2019). These mechanisms can inform the creation of adaptation pathways that provide insights into options, lock-in possibilities, and path dependencies and support decision-making on long-term adjustments. Adjusting means making new assessments, for example, as a continued part of the Delta Programme.

For long-term investments, it is important to consider that the agriculture and energy transition as well as ongoing housing challenges place different requirements on the soil and water system. Storage of water takes up space. Favorable locations for housing can often also be combined with the collection of water from extreme precipitation. To assess these adjustments, it is important to understand the barriers and synergies between different interests and needs. As an example, from the point of view of flood risk management and freshwater management, closing the Waterweg near Rotterdam is a plausible solution. But, this is not the case from the perspective of the accessibility of the port of Rotterdam. For drought control the water storage purposes, it should be as full as possible with water. For flood risk management purposes, the space should be free of water to temporarily store as much precipitation as possible. Evaluation of tradeoffs is an integral part of long-term investment planning.

Conclusions

Collaboration will be an important priority for the Netherlands going forward, in terms of upstream development, broader macroeconomic policies and investments, and to learn from other regions who have deeper histories with water scarcity issues. It is essential to cooperate across borders with countries such as Belgium, Germany, and Switzerland. Distribution of scarce water with neighboring regions will become increasingly important to become water resilient in the future, and iInitiatives such as the International Commission for the Hydrology of the Rhine Basin (CHR) are already contributing to this effort.

Although drought is a relatively new problem for the Netherlands, the potential for water scarcity problems are being integrated into how the country approaches older concerns around flooding and inundation. Fundamental shifts are occurring in how the country views resilience as a strategy and then implements that strategy at more local levels. Challenges remain, such as how to balance investment, governance, and tradeoffs between these risks. “Complete” protection from both threats is not possible, but new tools can ensure that the Netherlands retains a high standard of living, remains attractive to investment, and prospers even as an uncertain climate continues to evolve in unexpected ways.

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Water Resilience for Economic Resilience in Spain: A Critical Crossroads

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Key Messages

- Spain's economy is significantly dependent on natural resources, particularly water, the availability of which is progressively decreasing due to climate change.
- Climate change projections indicate a gradual decline in water resources and heightened climate variability, including increased frequency and severity of droughts and floods. This is coupled with escalating temperatures, greater evaporation losses, and an increased demand for water in irrigation and agricultural applications.
- The economy of southern Spain is strongly reliant on agriculture and tourism, both of which require the scarce water resources that are under threat from climate change. Tensions emerge between agricultural expansion and other industries, such as tourism, biodiversity preservation, energy generation, and urban applications.
- The energy sector, especially hydroelectric and biomass, faces significant vulnerability to water availability challenges. Uncoordinated reactions to water insecurity are undermining resilience

against future disruptions while water diversification initiatives such as transfers and groundwater utilization have inadvertently intensified water insecurity and diminished water resilience.

- Desalination and wastewater reuse exhibit promise; however, they are impeded by substantial costs and preferential treatment towards freshwater sources.
- The growth of Spain's economy has relied on extending water supply facilities and infrastructure, which have underperformed. Water management organizations are adapting to enhance water distribution, entitlements, and cross-sector collaboration, aiming to harmonize economic and environmental requirements.

Introduction

Spain is a relatively affluent economy that has relied heavily on natural resources throughout its history. The case for water reliance in Spain refers to an overarching adaptation problem of managing a unique resource with limited (when not diminishing) supply, set against the backdrop of increasing uncertainty due to climate change. The scope of changes experienced is already intense and potentially irreversible. Some aquatic ecosystems may become unable to continue to carry out their current functions, including services such as water provision that are integral to the economy itself (Marshall, 2013).

Spain is certainly at a crossroads for water that needs to be given high priority by economic decision makers. The structure and stability of the economy is at stake, affecting economic sectors in different ways depending on their location.

Climate change scenarios, despite their uncertainty, point to a progressive reduction of water resources in Spain. In the worst-case scenario, an approximately 24 percent reduction in average river flow is forecast for the end of the century with respect to the reference series 1961-2000, with possible reductions from 30–40 percent in the most sensitive areas. The reduction in aquifer recharge is estimated in similar proportions (NCCAP, 2020). There is also a substantial decrease in snow reserves that naturally regulate the water cycle.

All studies also predict an increase in climate variability. This points to an expected increase in the risk of droughts, which will be more frequent, longer, and more intense, and floods, with more frequent swells and higher peak flows (NCCAP, 2020). Episodes of torrential rain may be accompanied by geomorphological imbalances in basins, which may lead to a more accelerated siltation of reservoirs, with the consequent reduction in their capacity, accentuated by the need for flood mitigation measures. It is expected that 50 percent of flood-prone areas will be worse off. Furthermore, hydraulic infrastructures have been designed with safety margins that, in some cases, could be exceeded because of climate change.

Rising temperatures will also increase evaporation losses from reservoirs, which could double in the coming decades. The increase in evapotranspiration because of increases in temperature, together with the possible extension of the irrigation season, will lead to more demand for irrigation and agricultural uses, which already account for more than 70 percent of total demand in Spain.

In addition to agriculture, the energy sector is highly exposed due to its dependence on water availability. The expected impacts are relevant, and of a negative nature, in the hydro and biomass sectors. A significant reduction in hydroelectric production is expected as a consequence of reduced river flows.

The negative consequences of spontaneous, individual, reactive and unplanned responses to water insecurity are already visible in the most water stressed parts of the country. The main examples are the race to exhaustion in the use of groundwater, the illegal water markets, and the investments in new irrigation projects, whether legal or unauthorized. These responses to more scarce and more uncertain water resources can only come at the expense of reducing resilience to existing uses and future shocks. A planned, anticipated, and coordinated response is a basic precondition to restore the water resilience of important regions of the Spanish economy.

Water Exploitation in Spain

All Spanish basins suffer a certain degree of water stress. Around half of the Spanish territory, the Mediterranean basins, and Atlantic Andalusia currently suffer from severe water stress, which, combined with the typical irregularity of the Mediterranean climate, entails significant exposure to droughts.

The most serious case is that of Segura where "normal" demand is 132 percent of average annual resources, despite the contribution of transfers from other basins, desalination, and direct and indirect reuse. These extremes do not hide the high exposure of the severely water-stressed basins of the Jucar (95 percent), the Guadiana (62 percent), the Ebro (59 percent), and the Guadalquivir (55 percent) (Pulido-Velazquez et al., 2021; Marcos-García and Pulido-Velazquez, 2017).

Water in "the Model" of Economic Development

Water has always been a critical factor in Spanish economic development. Despite low and variable rainfall throughout its history, Spain has been able to harness the potential of water for economic development mostly for agriculture, power generation, tourism, and urban development. The other side of the coin is that the Spanish economy, and more particularly its most competitive areas (and those that have proved to be more resilient to the current world economic crisis such as agriculture and tourism) are heavily exposed to changes in availability of water resources.

Freshwater sources in Spain are intensively used, mostly in the most water scarce areas where populations and the most water-intensive activities tend to concentrate (Pulido-Velazquez et al., 2020). In all these places, local incentives and comparative advantages have triggered expansions in water demand that cannot be met with the renewable resources at hand. This is the case of the Mediterranean basins in Spain that require, on a regular basis, a quantity that largely exceeds their long-term water renewable resources. Under these conditions of water development, a binding condition for economic progress has required comparatively higher levels of infrastructure investment and sophisticated institutional arrangements from the onset.

Infrastructure has generally expanded water supply services everywhere and at the required volumes, widening opportunities, reducing production costs, and providing water, energy, and food security while allowing for the concurrent progress of all other sectors in the economy (Cook and Bakker, 2009;

Grey and Sadoff, 2007; Vörösmarty et al., 2021). Gradually, the marginal return of projects has decreased as the supply of water is more or less taken for granted and waterborne (and other water-related) risks are abated.

Few other places in Europe offer more convincing evidence of the importance of water for economic progress. Harnessing the productive potential of water has traditionally been a major challenge for economic development in most of the Spanish territory. Apart from the Atlantic catchments in the North, Spain presents all the features of a semi-arid Mediterranean climate with low rainfall (85 percent of the EU average (EEA, 2014)) and a high potential evapotranspiration (amongst the highest in the continent) that make this country the most arid in the EU, with an annual runoff half the EU average (CEDEX, 2017). High inter-season and inter-annual variability increases the management complexity of Spain's hydrological resources.

Historically, the main strategies of river basin authorities have focused on supplying water services to support areas of the economy including population change, urban growth, irrigation development, manufacturing activities, etc. The main objective of water policy consisted of finding inexpensive and reliable means to meet water demands.

Infrastructure was designed, built, and operated with the best knowledge at the time and assuming the normal variance of precipitation patterns around normal or average levels of rainfall. With the benefit of hindsight, ex-post evaluations show all water storage systems have performed below expectations for two main reasons: the lack of coordination across sectors and the overestimation of future water resources.

Addressing water scarcity has involved incentives to increase water availability by transferring water from further away territories. Paradoxically, water transfers have been more successful in increasing water demand than in increasing water resilience in water-scarce areas. They have also performed below expectations in adding more water to the balance. More recently, water desalination has become part of the supply mix. Installed capacity today is at 5 million m^3/day. Desalinated water is used as a buffer stock during drought events.

Water institutions have evolved throughout time while dealing with issues such as water allocation, definition, and enforcement of water use rights (Mathews et al., 2022; Grey et al., 2013). Other focal areas of water institutions include making norms, providing basic water services, monitoring water quality, developing technical skills, and coordinating investments as part of a progressive strategy of economic development (Garrick et al., 2019). This supply-oriented modus operandi is currently in a transition towards a new one aimed at making all water services used by the economy consistent with the preservation and adequate protection of the ecological status of water bodies.

The Importance of Water As an Economic Asset for the Different Sectors of the Economy

Agriculture comparative advantages

The Spanish economy has many different competitive advantages in specific sectors. In agriculture these advantages include a relative abundance of arable land. Spain has 261,000 km^2 of agricultural land — the largest in the EU only after France — representing 52.9 percent of the total area as compared to the EU average of 43 percent (EUROSTAT, 2022). Spain also benefits from an above-average amount of daylight hours and below-average labor costs (in terms of the EU). It is also partly explained by an elastic labor supply fed with immigration for many years. Still, water is the most critical and scarce factor for agricultural production.

The economic importance of agriculture is higher in water-stressed areas

The export-oriented commercial agriculture that dominates water-scarce Mediterranean basins in Spain requires more and more sophisticated inputs and labor skills, follows modern entrepreneurial practices, and supplies basic commodities to a complex and competitive agrifood manufacturing and logistics industry. On the contrary, traditional agriculture requires limited labor and manufactured inputs. Its management practices do not demand sophisticated commercial and financial services and its output does not feed complex industrial processes or supply chains. It has other benefits for biodiversity conservation and leisure activities, including tourism.

Since water is the main driver of the transformation of the agricultural model, this in turn has become the basis of a complex economic structure. In regions like Andalusia or Murcia, the direct contribution of agriculture to the regional output and employment (4.2 percent and 4.5 percent, respectively) might be low (although higher than average), but its indirect and induced impact over the whole production chain make it the central piece of the existing income and employment opportunities. For example, in Andalusia it is estimated that every additional euro generated by the sector generates two euros in the economy (output multiplier), and one job is created for every EUR 25,000 of additional output generated by the sector (Perez Blanco et al., 2010). In addition, this water-dependent sector has also performed better than the overall economy during recent crises. The employment share of agriculture in Murcia, Andalusia, and Valencia grew from 6.9 percent, 8.4 percent, and 2.8 percent in 2008 to 7.4 percent, 10.4 percent, and 2.9 percent in 2011, respectively. As a stark example, during this period agricultural employment in Murcia grew by 10.6 percent while the total employment rate declined by 10.6 percent overall.

Publicly coordinated water investments are associated with significant scale and scope economies (see for instance González-Gómez et al., 2014, for domestic water services). In other words, the social and economic returns of water development (indirect productivity) in the early and intermediate stages of water development are substantially higher than financial returns as perceived by individual users (apparent productivity). Economic returns of water development for parts of the Andalusia Region may be 3.1 times larger than its financial returns in the case of water for irrigation (92 percent of water consumption). In turn, this economic growth powered by water investments has the potential to induce significant water savings in the case of the manufacturing industry (Molinos Senante et al., 2021).

There are substantial differences in the productivity of the irrigation systems in water-scarce regions and those in relatively abundant regions. This explains the significant differences in the technical efficiency ranging between 81 percent for the Andalusian Mediterranean River Basins and 69 percent for the Guadalquivir River Basin compared to those of the relatively water abundant northern basins (between 53 percent in the Galicia Coast River Basin and 57 percent in the Ebro River Basin) (ESYRCE-MAPA, 2020).

Changes in irrigation techniques have been significant during the last decades. This has improved productivity. In 2002, gravity irrigation represented 40.5 percent of irrigated surface, sprinkler irrigation 18.4 percent, and drip irrigation 34.3 percent (other irrigation systems accounted for 6.9 percent of irrigated lands); by 2020 the more efficient drip irrigation already represented 54 percent, sprinkler irrigation 23 percent, and gravity 23 percent (ESYRCE-MAPA, 2022).

Competitiveness of Tourism

In 2021 Spain was the number one destination in Europe for international tourism with a share of 15 percent of the total number of nights spent in tourist accommodation establishments across the EU (EUROSTAT, 2023). The number of international tourist arrivals in Spain for 2022 was 71.6 million (INE, 2022). The economic boom of the last decade boosted the availability of rooms (which grew by 32.1 percent since 1999 until the sudden decline of the economy in 2008) (INE, 2014) and second residences (which grew by 87.7 percent in the period 2001–2011) (INE 2020). In 2022, the number of people affiliated with Social Security from the tourism industry amounted to more than 2.4 million, or 12.2 percent of the total (TUESPANA, 2023), a figure that reflects its importance in the national economy.

The direct contribution of the tourism sector to the Spanish economy was EUR 97.1 billion (8 percent of GDP in 2021). It included 2.3 million jobs, or 11.4 percent of employment in Spain (INE, 2022). Employment is even higher (up to 18 percent) when considering all inputs and the complementary services used by this industry (IET, 2020).

Tourism is concentrated in the dry season (i.e., summer months) and in the most water-scarce areas. This season coincides with the holiday period of European visitors. Almost 70 percent of total tourism is concentrated in the islands and the Mediterranean coast. Two of the main mass tourism destinations in Spain (and the first and fourth top 20-European tourism destinations in terms of nights spent), namely the Canary and the Balearic Islands, do not have permanent rivers.

The development of storage and desalination infrastructures combined with groundwater has provided a reliable supply of water services, which is a critical input for tourism and for the development of accommodation and amenities such as swimming pools, gardens, and golf courses. There has also been an increase in the demand of complementary services in the tourism package, such as food and beverage, travel agents, transport, banking, and other economic activities that help sustain the local economy.

Increasing competition for water resources along with reductions in water availability and pollution from intensive agriculture production — which has developed in the same regions of Spain as those preferred as tourist destinations — are already leading to financial losses in the tourism sector. This is the case in the area of the Mar Menor. The Bank of Spain estimated that home prices in the Campo de Cartagena area diminished 45 percent in real terms since 2016 due to the ecological crisis of the lagoon (BDE, 2021). The Bank calculated a wealth loss of EUR 4,150 million in the region as compared with a scenario without the ecological crisis.

Energy production valuable but below expectations

The Spanish economy required 75 years and considerable resources to develop the existing hydroelectricity capacity. The installed potential is 16,000 Gigawatts. This is a remarkable record. But if we look at the actual electricity produced, it may seem a complete failure. After 75 years of hydroelectricity development, the whole system is only able to produce a fraction of the energy that was produced 75 years ago when these infrastructures were not in place. The difference is that back then there was water.

The general conclusion after 75 years is that the remarkable development of hydropower has been more effective in maintaining the production of electricity than in increasing or even stabilizing electricity production. This outcome would have been different if hydropower development had been coordinated with agricultural and urban development, reducing the need of heavy infrastructures and coordinating water demands. With time, once the margin for new infrastructure to ensure water supply has been narrowed by decreasing returns, this option to improve water resilience cannot be an option.

Pathways Toward a Water-Resilient Economy

The objectives of the water transition to a resilient and sustainable pathway in Spain are still a matter of discussion and will require reaching political agreements, as well as coordination of different policy areas.

Decoupling the economy: Structural transformation of the economy

With the existing resource constraints and overall generalized impacts on water, Spain cannot continue growing with the same rates of intensity of water use in the economy. It is essential to decouple growth from increases in the demand of water. To do this, the relative importance of the different sectors has to change, especially in those regions where climate change is going to affect the availability of water resources the most.

To date, the Spanish economy has not been successful in decoupling economic growth from water use. Although water use per capita has remained stable (770 m^3/capita/year in 2009 according to OECD (2012)), some river basins still use water in excess over long-term renewable resources. For instance, the Guadalquivir and Segura River Basin's ratios of water abstraction over renewable resources are 1.64 and 1.27 according Pulido Velazquez, et al. (2021) and the projections envisaged in the River Basin Management Plans do not show a change in this pattern. Although water demand in the Segura in 2021 was be very similar to that of 2009 (1,762.1 instead of 1,779.1 million m^3), water use is expected to grow by 5.2 percent (from 2,892 to 3,046 hm^3) in the Tagus River Basin, which supplies 17.3 percent of total water demand in the Segura (SRB, 2020).

Technological investments in decoupling the economy from water use have not always been successful. The National Irrigation Plan (2008) expected to be able to advance decoupling with projected savings of 3,662 hm^3/year and an investment cost of EUR 7.368 million (López-Gunn et al., 2012).

The overall conclusion is clear. To contribute to decoupling and to transition into a water resilient economy, water savings need to be transformed.

The drive of public budgets towards investing in infrastructure needs to be re-evaluated

The perception of water development and water investments generating economic growth as a key factor for rural development has led to the construction of bulky infrastructure designed to use resources as much as possible.

More needs to be invested in taking care of the existing resources or in protecting the water that is required for infrastructure to function properly. This requires an economic evaluation of water infrastructure decisions, comparing, for example, the cost-benefit ratios of different alternatives and analyzing their macroeconomic impacts. Benefits and macroeconomic impacts cannot be taken for granted.

There are other investments such as the protection of existing resources (and specially groundwater) and the diversification of water sources that are an opportunity to match water supply and demand while facing the deep uncertainties of climate change. They contribute to the goal of curbing water scarcity and provide an adaptive response to uncertain water supplies — provided that affordability concerns are addressed and adequate incentives are established.

Building a sustainable water portfolio requires rewiring policy decisions in the long term and making clear decisions over the size and composition of the water portfolio. Different sources of water should play different roles in the long term. Those decisions over the optimal water portfolio, prioritized on explicit economic criteria, need to be part of the adaptive policy pathways of the water transition.

Investing in a resilient future: Investing in co-benefits makes economic sense

Protection of groundwater must be a priority, not only because it is the most vulnerable resource due to the deterioration of its quality and increasing overexploitation, but also because it is a strategic resource for water management in situations of drought. It plays a fundamental role in the maintenance of aquatic ecosystems, providing the base flow of river systems. Its deterioration jeopardizes the environmental status of rivers and endangers the sustained provision of water services.

Increased groundwater depletion has opportunity costs. It is becoming unavoidable to invest in the much more expensive non-conventional water sources to ensure excess capacity in times of drought. This has effects in terms of costs of production, in the competitiveness of the economy, and opportunity costs in terms of allocation of the public budgets.

The recovery of the morphology and dynamics of watercourses is also an important investment for the future. It plays a key role in hydrological regulation and flood risk management. Actions such as nature-based solutions (NBS), sustainable urban drainage, including recovering meanders, reconnecting floodplains, renaturalizing watercourses, preserving wetlands, eliminating obstacles, promoting continuity, and recovering riverside forests should be promoted. These actions perform multiple functions and offer co-benefits such as reducing flood risk, improving biodiversity and the conservation status of ecosystems, recharging aquifers, protecting quality, reducing erosion, and improving soil structure.

Considering the marginal cost of the supplies to cope with droughts

Given the multiple uncertainties about water, it is important to recognize from the beginning that water transition would not be possible without adaptable policy pathways for harnessing the potential of opportunities to provide resilience to economic development. Flexibility could be facilitated by contingent and flexible water allocation rules for adapting water demands to available resources across time and space, improving adaptability while preserving the objectives of the water transition.

Diversification of water sources when properly designed and implemented could serve the objectives of the water transition. Water scarcity and the need to cope with more frequent droughts can be tackled with alternative sources at higher marginal costs (from reuse of reclaimed wastewater to desalination of brackish water and seawater). This is not a new option in Spain. Substantial improvement has been recorded regarding the increasing capacity to desalinate water. The installed desalination capacity is around 5 million m^3/day and could potentially supply water for a population of 34 million inhabitants (Zarzo, 2020).

However, given the high cost of desalinated water, its effective use has been limited in quantity. Less than one-fifth of installed membrane capacity is actually used, and it is reserved only for more valuable uses (mostly drinking water) in particular during dry periods. Non-conventional water is then used mainly for emergency situations, posing additional challenges for its financial sustainability, while overexploitation of freshwater sources may go on.

Assigning a substantive role to desalinated water in the supply portfolio is still a pending and a highly controversial issue. In practice, due to its relatively high cost, this source is reserved as a buffer stock for emergencies (i.e., droughts). This improves resilience to droughts although it represents a real challenge to the financial sustainability of operating plants.

Creating incentives to protect and conserve the resources we have

In the "business-as-usual" scenario, the incentives in place lead to the destruction of the cheap and easily available reserves of groundwater resources, which paradoxically are the most valuable as strategic reserves for the future. They are the ones best suited to act as buffer stock during droughts and to provide water security.

Water is a sector where scarce and unreliable goods are priced lower than their abundant and reliable substitutes, unlike microeconomic theory would suggest. In the business-as-usual scenario, continuous depletion of groundwater sources will take place until extracting reaches the price of alternative sources, even if alternative resources are available. There is then a pricing failure which translates into incentives in such a way that users prefer financially cheap but scarce and unsafe water sources rather than the financially expensive but relatively abundant and reliable alternative water sources. Should the problem not be recognized, the unavoidable transition from financially cheap to more expensive water sources would induce significant harmful effects on the environment and the economy. The real question is then how to preserve the "cheap" but most "valuable" resources, given that the baseline scenario can easily be anticipated, considering the incentives in place.

Considerable progress has been made thanks to the drought management plans in Spain. To some extent, they made drought response anticipated (rather than discretionary and reactive) and planned (rather than improvized) but needed to tackle the real problem: the control over an important part of the available water resources. Furthermore, higher constraints may also lead to higher incentives for over-abstraction, thus leading to lower buffer stocks and higher drought risk. These are clearly unwanted outcomes.

What incentives then may need to be established to provide water security so as to guarantee the resilience of the economy? How can incentives be created so that surface water abstractions by water users will remain close to renewable runoff (considering environmental flows) and demand in excess will be met from groundwater — exploited under unsustainable patterns but still less expensive than non-conventional sources?

The “use it or lose it” kind of incentives occur when farmers and other agents perceive the value of water but do not have any alternative to using it. This increases or sustains water demand, even when it is greater than long-term water supply. Prevailing incentives push sectoral demands up and make it difficult to close de facto the river basins to accommodate current uses within the range of available water resources. Perversely the “use it or lose it” framework may mean that new infrastructure is executed to consolidate the right to use local water resources.

Incentive and pricing schemes for a water-resilient economy

In this context it is important to make clear that water prices, subsidies, fees, and other financial instruments are not inherently good or bad but are simply instruments or means to the ends of water policy. Indeed, these instruments should provide the revenues needed to the financial sustainability of the provision of valuable water services. In addition to that, from an economic and policy standpoint, they should promote the behavioral changes needed for the water transition towards a water-resilient economy and discourage actions that harm water resilience.

The most important water policy challenge nowadays still consists of aligning the multiple individual decisions on using and preserving water with the common societal goals of paving a transition towards a resilient economy. In most cases what is rational from a private point of view is not necessarily such from a social or economic perspective.

Significant progress has been recorded so far in adapting water prices and making cost recovery of operational and capital expenditures more transparent. However, this progress refers mainly to urban water services.

Water prices are low when compared to the cost of marginal resources. Further progress is required in covering resource costs (in particular that relate to water scarcity) and environmental costs. There are frequently no adequate incentives for farmers to use water efficiently as water consumption is, to a large extent, not metered and therefore water charges are not linked to real consumption. There is evidence to show that farmers are reluctant to pay more for water. But contrary to perceptions, they report in some studies to be willing to pay an excess price between 0.16-0.18 €/m^3 for water security (Sala Garrido et al., 2020).

Self-abstraction is not charged. The energy cost of withdrawal in some cases provides an adequate incentive to halt overexploitation. In others, it has not been high enough to prevent, for example, environmental external effects on wetlands and other protected areas.

When water supply reduces and it is increasingly uncertain, individuals are more willing to pay for water security. They might actually be willing to transform their productive system in order to use less water and reduce its exposure to water shortages. This can include a shift towards crops that are less vulnerable to water deficits or, for example, they might be willing to pay for an insurance policy covering drought losses (Perez Blanco and Gómez, 2014). In this context, the role of pricing and cost-recovery mechanisms (as financial instruments to ensure the right incentives are in place), is still of paramount importance. Prices should actually make the best out of current opportunities through bridging efficiency gaps, inducing shifts towards less water-intensive activities, and using alternative supply sources to mitigate scarcity and increase the water resilience of the economy.

Economic activities and cities must be rewarded for contributing to water resilience and charged for worsening water security. Prices need to be designed as part of a decision-making architecture to lead people to make decisions that are consistent with an overall objective of economic resilience and environmental improvement.

Improve the existing insurance schemes

Actually, the main source of farmers' security is groundwater. Nature is paying the price of farmers' exposure to droughts. Production during drought years has been sustained at the expense of groundwater over-exploitation. Moreover, the prices of agricultural products have been seen to increase during droughts, leading to greater benefits for farmers.

However the financial system may be a better option than the overexploitation of groundwater during droughts. Some alternatives are being considered. Developing new insurance schemes, such as a drought insurance, might be a means to make the financial system stand up to preserve local income in drought-prone areas and make a real contribution to recover critical groundwater assets by freeing them of the duty of serving as income security instruments.

Use subsidies wisely: Getting subsidies right

The role of incentives is critical to deal with the affordability concerns arising anytime a new solution with the potential to contribute to the water transition comes into play. These concerns are the most visible barriers to the extended use of desalinated water, the adoption of water efficient devices, and the adoption of NBS and other water conservation practices in cities and rural areas.

Many alternatives can be used to overcome affordability barriers, but all of them should be implemented on the condition that the beneficiaries make a sizable contribution to the water transition. Similar to the energy transition and to the EU Green Deal, all the financial instruments to overcome affordability concerns should be integrated into a just transition strategy.

No doubt, affordability concerns need to be managed as a critical component to make the water transition politically acceptable in water scarce areas. But, dealing with affordability by subsidizing water services may increase water use and extend tensions to these new sources. In other words, subsidies make sense in a process of transition when they reduce pressures on over-exhausted water bodies (e.g., groundwater) or when they protect wetlands and biodiversity — providing co-benefits to the economy and society in a pathway towards more sustainable water use.

In relatively water-abundant areas, subsidies to capital costs of infrastructure and water supply systems lead — in a mature water economy like Spain — to the use of water in very marginal lands. This can create environmental impacts and reduce resilience of all other existing or potential uses for very little contribution to the economy. In individual plots, low water prices have resulted in production systems using water intensively, with returns on investments below the capital and operating costs of the infrastructure, without generating locally the types of economic spinoffs that may have justified these investments.

Increasing resilience for farmers needs to make financial sense

The agricultural sector does not only suffer the impacts of climate change, but its own practices can be a cause of increased vulnerability. There are practices and measures that can minimize this vulnerability, including:

- regenerative agriculture
- hydrological-forestry restoration in areas at high risk of erosion
- promotion of native forest crops to replace agricultural crops in flood-prone areas
- crop rotation and diversification
- maintenance of vegetation covers and the incorporation of pruning remains into the soil for woody crops
- saving and efficiency measures aimed at reducing net water consumption
- a commitment to crop varieties or livestock species that are better adapted to the impacts of climate change.

Promoting these practices requires financial incentives in irrigation planning as well as coordination of agricultural policy and hydrological planning. Some of these practices and measures have double benefits for climate change mitigation and adaptation: fixing CO_2 and acting as agricultural sinks. In Spain they have been included in the National Common Agricultural Policy Plan and in the National Integrated Energy and Climate Plan (2021–2030) together with other measures that promote the reduction of GHG emissions.

Conclusions

Water security has always been a defining challenge for Spanish economic progress. Perceptions of water security issues may have changed with time, from guaranteeing a minimum supply of water with the little resources available in the past to increasingly being able to respond to the irreducible uncertainties brought by climate change over future water supplies.

Many lessons can be learned from a century of water supporting economic progress in a country where water security has been a fundamental challenge. These lessons are relevant for providing new and more resilient responses to the emerging challenges of adapting to climate change while curbing the detrimental trends inherited from traditional water development and use. The ability to move towards a water-resilient economy and better respond to increased climate risk — a clear national economic and social priority given the water policy challenges — is determined by the ability to act and plan collectively.

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Bolivia's Path to Economic Resilience: IWRM as Key Contributor for Sustainable Development

by Ana Cecilia Escalera

Key Messages

- Bolivia faces a looming water crisis with demand projected to rise by 15–36 percent by 2036, largely driven by agriculture, which accounts for 92 percent of freshwater withdrawals. This increasing demand is exacerbated by underestimations in water usage calculations and ambitious plans to double irrigated land, putting additional strain on already limited water resources.
- Climate change is intensifying Bolivia's water vulnerabilities, causing alarming glacier retreats that impact critical water supplies for cities, while also increasing the frequency and severity of droughts and floods.
- Bolivia is shifting its economic focus towards becoming a major energy player in South America, with significant investments in hydropower and lithium. These shifts disrupt local hydrological patterns but also have the potential to exacerbate water scarcity, particularly in regions already vulnerable to climate change. This could lead to a range of socio-economic consequences.

- IDB studies indicate that water-related events could significantly impact Bolivia's GDP, necessitating increased investment in water infrastructure and management.
- As a tool to achieve water sector goals, the National Watershed Plan (Plan Nacional de Cuencas (PNC)) emerged. One of the main reasons for creating the PNC is the absence of a clear and strong water policy. This has led to fragmented management of water resources and scattered regulations with a lack of coordination between drinking water and other sectors, which made it difficult to manage water resources effectively and plan for the long term.
- Bolivia's PNC has made strides in addressing hydro-social conflicts and enhancing investment efficiency in watershed management, but faces challenges in subnational and intersectoral coordination as well as limited active involvement from the private sector and civil society. These gaps hinder the policy's effectiveness in building water resilience and adapting to climate change challenges.

Introduction

Despite the progress in reducing poverty levels over the past several decades according to World Bank data, Bolivia remains one of the most economically challenged nations in Latin America. Historically, its economy has been heavily reliant on the extraction and exportation of natural resources, particularly in the fields of gas, mining, petroleum, and agriculture (WFP, 2023). As of 2022, the composition of the country's GDP is distributed as follows: Services sector accounts for the largest share at 52.4 percent, followed by Manufacturing at 16.3 percent, Agriculture at 13.9 percent, Mining at 8.5 percent, and Commerce at 8.1 percent (SIP, 2023). In recent years, there has been a notable shift towards the energy sector, driven by a government-backed initiative to advance an extensive agenda focused on the creation and export of electricity, which includes the construction of hydroelectric plants for raising the contribution of hydropower in the national energy mix from 15 percent in 2019 to a remarkable 70 percent by 2025 (CIF, 2023). As a result, Bolivia aims to emerge as both a dominant energy player in South America and a key energy exporter within the region. Moreover, due to Bolivia's significant lithium reserves, the extraction of this mineral is poised to assume a pivotal role in the country's economic strategy, particularly with the government's efforts to enhance its standing in the global lithium market (AP News, 2023).

Bolivia holds remarkable topographical and climatic diversity, spanning from the lofty heights of the Andes Mountains at 6,500 m above sea level, to the Inter-Andean Valleys, and further descending to the lowlands of the Amazonian and Chaco regions, resting at an altitude of less than 500 m above sea level. This geographical variation categorizes Bolivia into three distinct topographical and climatic zones: the arid highlands and Andean region to the west, the semi-tropical valleys in the middle, and the lush tropical lowlands to the east (World Bank, n.d.). These distinct zones give rise to a mosaic of intricate ecosystems and habitats, fostering rich biodiversity (LACGEO, 2023).

Bolivia's strategic location and susceptibility to dramatic climate fluctuations driven by the El Niño-Southern Oscillation (ENSO), which have been exacerbated by the effects of climate change, generate severe natural challenges including heavy rainfall, floods, and droughts. Compounding these issues, the nation faces rapid population growth, inadequate urban planning, and insufficient control measures. Consequently, this has led to haphazard urban development, characterized by high levels of physical and social vulnerability. These circumstances have precipitated significant degradation of urban living conditions, further exacerbating the ongoing economic, social, and environmental crises. The combination of substantial threats and vulnerabilities has created a high-risk scenario, fraught with the potential for substantial economic losses and far-reaching impacts on the population in the face of natural disasters.

Climate Change and Water in Bolivia

The climate crisis in Bolivia presents significant dangers to human well-being, economic stability, social cohesion, productivity, and the environment. Based on an analysis of the consequences of extreme climatic occurrences and their interconnected socio-economic factors, the 2021 Global Climate Risk Index (CRI) ranks Bolivia in the tenth position among the most susceptible nations globally. Oxfam (2009) provided a fair description of the key aspects that explain this high vulnerability:

1. It is one of the poorest countries in Latin America and suffers from one of the worst patterns of inequality. The national poverty rate is 37.5 percent, positioning the country as the second poorest country in the South American region, just below Venezuela. Low-income groups in developing countries are the most exposed to climate change impacts.
2. Located in a climatically volatile region, it is one of the countries in the world most affected by natural disasters in recent years.
3. More than half of the country is Amazonian, with high levels of deforestation which adds to the vulnerability to flooding. From 1985–2022, the Amazonian Forest in Bolivia was reduced by 7.4 percent, equivalent to 1.5 million hectares (Mongabay, 2023a).
4. It is home to about 20 percent of the world's tropical glaciers, which are retreating more quickly than predicted by many experts.
5. It is one of the most bio-diverse countries in the world, with a wide variety of ecosystems that are vulnerable to different impacts from climate change.

The water challenges confronting Bolivia have been significantly exacerbated by the far-reaching impacts of climate change. Over the span of more than eight decades, Bolivia has experienced a concerning increase in its average annual temperature, with a rise of 0.1 °C per decade. This trend has resulted in an alarming retreat of glaciers (CIF, 2023), with a particularly bitter instance being the vanishing of the iconic Chacaltaya glacier near La Paz in 2009. This retreat holds profound implications, especially for the approximately 230,000 Bolivians residing in high-altitude regions, whether in urban or rural settings, who rely on the meltwater from these glaciers for more than a quarter of their monthly domestic water requirements. This number increases to approximately 1.5 million people during the peak of the melting season. Consequently, the receding glaciers introduce a notable risk to urban centers such as La Paz and El Alto, as these glaciers constitute a substantial source of their potable water supply (Oxfam, 2019).

Droughts and floods have escalated in both frequency and intensity over recent years, relentlessly impacting the nation. According to the National Meteorological and Hydrological Service of Bolivia (SENAMHI), national registers indicate that instances of flooding and drought have become increasingly frequent and severe in the past decade (Mongabay, 2023b), associated with the shifting climate patterns that are leading to notable alterations in precipitation dynamics. This is consistent with data from databases such as DesInventar (2023), which shows evidence of an increased number of drought and flood declarations at the municipal level in Bolivia. Projections outlined in the 2015 Bolivian Nationally Determined Contributions (NDCs) foresee a worrisome future by 2030, with up to 24 percent of Bolivia's landmass susceptible to recurrent flooding and another 27 percent grappling with prolonged periods of drought.

Ravaging Economies: The Impact of Floods and Droughts

Flooding has notably intensified in the lowlands of northeastern Bolivia due to the extensive river systems and flat terrain, making this region particularly vulnerable. Urban areas like Trinidad and Cobija have borne the brunt of significant flooding, causing disruptions in infrastructure, homes, and people's lives. Around 43 percent of the population resides in flood-prone areas, according to estimates from the Ministry of Development Planning. In 2015, one of the most impactful flood events in the past decade occurred, resulting in an estimated loss of US$ 450 million and affecting over 300,000 individuals. The consequences of this event were far-reaching: nearly 18.6 percent of national roadways were forced to close, water and sanitation systems in the Bolivian Amazon were compromised, leaving many without essential services, and the destruction of 120,000 hectares of crops led to an approximate loss of 445 metric tons of production (UDAPE, 2015). Between 1990 and 2014, floods accounted for 37.3 percent of deaths and 17.5 percent of economic damages caused by natural disasters (Nunez and Verbist, 2018). Research suggests that climate change related flooding could incur a US$ 93 billion toll on public infrastructure, with yearly costs averaging US$ 3.113 billion. Furthermore, agricultural and livestock losses might amount to US$ 82 billion, averaging around US$ 2.726 billion annually (Ishizawa et al., 2017).

The ThinkHazard! Platform from the World Bank designates Bolivia as notably susceptible to droughts, with a recurring pattern expected every five years on average, particularly concentrated in the Andean regions. This concern is magnified by Bolivia's past experiences of significant socio-economic losses from drought events. Should the frequency and intensity of these events increase, the resulting losses could be even more severe. According to the Drought Atlas in Latin America and the Caribbean (Nunez and Verbist, 2018), between 1990 and 2014, droughts were responsible for 5.7 percent of deaths and 15.8 percent of economic damages from natural disasters. During the same period, approximately 773,000 hectares of agricultural production were affected by droughts. The country faced its most severe drought in 25 years between November 2016 and February 2017, impacting 177,000 families, devastating over 624,000 hectares of crops, and leading to a state of emergency in seven out of the nine country regions (UNTC, 2016). In addition to climate change, inadequate water management, rapid urban growth, and contamination of water sources from extensive agricultural and mining activities in drought-prone areas have all contributed to exacerbating the impacts of droughts (SEI, 2018).

Studies conducted by the IDB estimate that losses could amount to at least 4$ of the GDP for events that are highly probable and moderately extreme; these losses undoubtedly correspond primarily to extreme phenomena. Losses would constitute 2.5 percent of the GDP for extremely dry events with a medium probability. The most pronounced impacts on the GDP would occur with the incidence of extreme floods with varying probabilities, ranging from 2.76–3.08 percent of the GDP. The lower limit of a 2.76 percent GDP impact is comparable to the public sector deficit, while the upper limit of a 3.08 percent GDP impact is akin to the external current account deficit and the country's fiscal deficit, prior to the COVID-19 contingency.

A straight-forward conclusion can be obtained from this: stimulation of investments and public expenditure stimulation in the water sector will need to be scaled up to reduce the burdens of water-related shocks on economic development. This could involve establishing dedicated funds for water infrastructure development, maintenance, and resilience enhancement. Furthermore, encouraging private sector involvement through partnerships and incentives can unlock additional funding and expertise. By fostering public-private partnerships, the private sector can contribute innovative solutions, advanced technologies, and efficient management practices that amplify the effectiveness of water-related initiatives. Such collaborative efforts hold the potential to not only fortify economic development against water-related challenges, but also to ensure sustainable access to water resources for communities and industries alike. Additionally, comprehensive policies should be designed to attract investments and ensure their efficient utilization, fostering innovation in water management technologies and practices.

The Other Side of the Coin: Socio-economic Development Exacerbating Water Challenges

Research indicates that the demand for water in Bolivia is projected to be 15–36 percent higher in 2036 compared to 2011. This rise is already noticeable, causing supply to fall short in certain areas such as El Alto (SEI, 2018). At the same time, various economic sectors are escalating their water needs.

Agriculture stands as the predominant consumer of water, accounting for a significant 92 percent of total freshwater withdrawals. This is trailed by water supply at 6.5 percent and the industrial sector at 1.5 percent (World Bank, n.d.). Agricultural water withdrawal shares are set to rise with a projected doubling of irrigated land outlined in National development plans (MMAyA, 2022). It is crucial to recognize that the availability of water for agricultural needs isn't solely tied to cultivated surface area. Around 33 percent of Bolivia's total land area, including grasslands for livestock use, permanent pastures, and rain-fed crops, uses water not officially classified as agricultural use in Bolivia. This underestimation in sector-specific usage calculations highlights the potential strain on water supply for other sectors (FAO-AQUASTAT, 2023).

Water plays a pivotal role in Bolivia's energy sector. As of 2019, the country possessed an installed hydropower capacity of 725 MW. The National

Electricity Plan 2025 aspires to elevate the hydroelectric share in the energy mix from 29 percent to 70 percent, supplanting natural gas (IHA, 2019). As this sectoral water consumption grows, the risk of demand surpassing supply intensifies, rendering Bolivia more susceptible to severe water crises. Within this context, initiatives geared toward climate change mitigation, like replacing gas with hydropower, could jeopardize climate resilience efforts if not well planned. The implementation of hydropower projects has the capacity to reshape local hydrological patterns to harness clean energy, disrupting downstream water availability and impacting not only communities and urban areas but also agriculture. This risk is particularly pertinent in regions already dealing with water scarcity due to the changing climate. Furthermore, inadequately planned hydropower developments could heighten the susceptibility to specific climate-related events. For instance, mismanaged dams might exacerbate flooding during episodes of intense rainfall or even precipitate dam failures, leading to considerable destruction downstream. This concern is particularly critical in regions where the changing climate has amplified the intensity of rainfall patterns.

The implications of transitioning to a lithium-based economy also pose a significant threat to Bolivia's water resources. While the government's endeavors to position Bolivia at the forefront of the lithium market hold promising economic prospects, they also raise concerns. This is particularly true given that the extraction of lithium demands approximately 2.2 million liters of water per ton. On top of the water crisis that the region is already suffering as a consequence of increased frequency of droughts and glacier retreat, such extensive water usage within the extractive industry has the potential to further exacerbate the already limited water resources in the entire region and jeopardize the prospects of a viable future for local communities.

In essence, the interaction between climate change and socio-economic development strains water availability in Bolivia. Updated NDCs indicate increased sectoral water use due to climate actions, despite efforts to enhance water efficiency. Water scarcity in Bolivia results in food insecurity and substantial socio-economic consequences. Highland communities (more than 1.25 million people, approximately 46 percent of Bolivia's rural population, according to the latest National Census (2001)) often consume less than half of WHO's recommended water intake, leading to increased illness. Changing seasons disrupt traditional crop planting, livestock management, and decision-making. Droughts in the Bolivian Altiplano are damaging farmlands, impacting farmers' livelihoods and food access (Escobar & Purkey, 2013). This has triggered hunger, malnutrition, migration, and local conflicts (Canedo Rosso, 2019). Furthermore, water insecurity, particularly affecting households led by women, induces emotional distress. As Bolivia's vulnerability to water crises intensifies, these impacts could escalate in both frequency and severity.

Water Resilience for Economic Resilience: IWRM Leading the Way

Climate change and socio-economic development have increasingly strained water systems across the country. Recognizing the importance of proper water resources management and the need of proactive actions to mitigate the effects of climate change in order to protect livelihoods and socio-economic conditions, significant changes have been made to Bolivia's legal and institutional water framework in the past two decades. Several policies, plans, and programs have emerged in Bolivia in recent years. In 2013, the Bolivian government introduced the Patriotic Agenda 2025, outlining 13 key pillars for the country's development over the next 12 years (Vargas et al., 2013). Building on this, the Economic and Social Development Plan within the framework of Integral Development for Well-Being (PDES) was established by the Plurinational State of Bolivia. The PDES methodically aligns goals with each pillar of the Patriotic Agenda and is consistent with the Sustainable Development Goals (Benavides et al., 2019).

Several PDES objectives pertain to the integrated management of water resources in basins and include actions across various sectors influencing the hydrological cycle. This necessitates a coordinated approach to water resource planning and (hydrological) disaster risk management at the basin level. The most relevant goals for the water sector include:

- **Ensuring universal access to clean water and sanitation services for Bolivians**. Given increasing pressures on water sources, it is recognized that protecting this right requires comprehensive planning for usage, source safeguarding, and watershed conservation.
- **Enhancing agricultural and livestock production systems**. This involves expanding irrigation, underpinned by basin-level water availability assessments to accommodate sector needs and other uses while preventing source depletion during droughts.
- **Developing hydroelectric power projects**. Emphasis is placed on comprehensive internal planning and basin management to sustain investments and enable the versatile use of regulation structures.
- **Integrated water and climate change risk management**. Strategic guidelines are set for implementing plans and actions in prioritized basins to coordinate and balance water use among different sectors.
- **Managing hydrological risks**. The objective is to reduce municipal vulnerability to adverse hydrometeorological and climatic events through risk management and climate adaptation actions, including the implementation of integrated early warning systems.

As a tool to achieve the water sector goals within the PDES, the National Watershed Plan (Plan Nacional de Cuencas (PNC) emerges. The PNC is conceived as a policy for the implementation of Integrated Water Resources Management (IWRM), a widely employed decision-making approach that facilitates coordinated development and stewardship of water, land, and associated resources across entire watersheds or river basins. Additionally, Bolivia has adopted a complementary strategy known as Integrated River Basin Management (IRBM), which places emphasis on the sustainable utilization of land and other natural assets within a watershed. Within the existing policy framework, both IWRM and IRBM stand as pivotal components in attaining water security.

One of the main reasons for creating the PNC is the absence of a clear and strong water policy. This has led to fragmented management of water resources and scattered regulations with a lack of coordination between drinking water and other sectors, which made it difficult to manage water resources effectively and plan for the long term (Llanova, 2020). The PNC has developed through Quinquennial Multi-Year Programs, which allow for evaluating past program results and learning from them to improve future plans. One key advantage of this cyclical policy approach is that it enables flexibility and the ability to adapt to current needs (Llanova, 2020).

The PNC comprises strategic components for its implementation. Those that have notable socio-economic implications are: 1) Strategic Basin Management and Basin Master Plans involving intergovernmental and interinstitutional coordination for natural resource governance, 2) Investments in IWRM for irrigation, water storage, and micro-watershed management, and 3) Hydrological Risk and Climate Change Management focused on preventive measures, watershed management, early warning systems, and cultivating prevention-oriented attitudes among authorities and the population.

The Good and Bad of Water Governance and Management: A Brief Review

The Good

The PNC addresses a crucial issue for the future of Bolivian society: it aims to resolve growing hydro-social conflicts arising from urbanization and activities in key sectors pressuring watersheds, essential for the country's sustainability and economic growth. The policy's adaptable formulation system, informed by its own implementation and changing social needs, ensures flexibility to address emerging challenges.

Progress in implementing the components until 2020 has varied, but overall, objectives have been met (Llanova, 2020). Challenges like funding gaps, conflicts in certain areas, weak institutions, and limited local awareness have hindered some policy components. On the other hand, factors such as the need for water policy, international cooperation, and viewing the policy as a learning cycle have contributed to its successful implementation (Llanova, 2020).

There is significant variation in the allocation of resources across different regions of the country, tied to a prioritization strategy for watersheds that enhances investment efficiency. Concerning the implementation components, investment in each of them amplifies the execution of the others due to their interconnectedness. An example of this is how investment in information improvement bolsters the establishment of River Basin Master Plans and enhances the capacities of various stakeholders. Quantitative evaluation of policy implementation benefits is difficult, especially considering that results are expected over the long term. Nonetheless, specific examples give an idea of the magnitude of these benefits.

For instance, through the implementation of hydrological risk management, defensive structures were constructed to safeguard agricultural lands and vital social and productive infrastructure. Moreover, this component facilitated a shift from reactive to proactive measures in disaster risk management, evident in the establishment of a national flood forecasting and early warning system, as well as a national drought monitor. Both systems have emerged as critical information providers for decision-makers across sectors, advancing the water sector's resilience and socio-economic development in the face of climate change challenges. This is especially important given that floods and droughts lead to significant economic losses, primarily affecting infrastructure and agricultural production, and therefore the economic impact of these initiatives could be highly positive. This is particularly relevant in the context of the agriculture sector's vulnerability to drought impacts. In this scenario, the insights provided by a drought monitor are indispensable for farmers and policy-makers. They enable anticipation of drought conditions, facilitating adjustments to planting schedules, implementation of irrigation strategies, and optimal resource allocation. This proactive approach can effectively avert substantial declines in agricultural output and stabilize food prices. The different phases of policy development are logically connected. As a result, policy formulation addresses the identified issues in the diagnosis and serves as a starting point for defining components that guide actions. The policy recognizes and emphasizes the importance of coordination between sectors and institutions, enhancing the link between watershed management programs and projects in various areas like sanitation, irrigation, and hydro energy.

The Bad

The sectoral policies for water resource management and disaster risk management have not been adequately embraced by subnational governments as part of their policy and vision for resilient territorial development. Despite the PNC granting leadership to departmental governments for its overall implementation, the lack of subnational involvement in policy design results in a lack of ownership for its execution. This highlights insufficient progress in decentralizing water and environmental management at the subnational level (Saaverda, 2021).

There are significant weaknesses in how water resource management instruments address intersectoral coordination. Intersectoral collaboration has been incipient within sectors (e.g., irrigation, drinking water, and sanitation). Mechanisms, instruments, and multisectoral investment regulations are needed to enable effective coordination between ministries for interventions in strategic watersheds. Adopting a watershed nexus approach could be highly relevant in this context (Llanova, 2020).

Moreover, there is a notable lack of active involvement from the private sector, universities, and civil society in the implementation of actions aimed at enhancing water resilience. Their role within platforms is primarily confined to advisory capacities, offering limited influence in the decision-making process. It is imperative to restructure the decision-making mechanisms within the platform, allocating a more prominent position to both civil society and the private sector in shaping water management decisions. Such a shift would enable the effective utilization of their expertise, innovative problem-solving approaches, practical execution capabilities, enhanced accountability, garnering of public support, consideration of long-term perspectives, and facilitation of transparent governance. Elevating their involvement in decision-making would facilitate the leverage of their insights and resources, consequently leading to the development of more impactful and sustainable water management strategies, aligned cohesively with overarching societal requirements.

Looking Forward: What Has Been and What Can Be Done to Increase Resilience for an Uncertain Future

Water is a crucial input for socio-economic development, making its proper management and preservation critical for the resilience of countries. Responsible water management not only ensures a continuous supply for productive activities like agriculture and industry but also helps mitigate the impacts of extreme climate events, thereby promoting stability and sustainable growth for communities and the economy as a whole.

A closer look at water resource management and usage in Bolivia highlights significant challenges. Precipitation varies greatly from year to year and season to season due to climate variations like El Niño and La Niña. Climate change is intensifying these irregularities, resulting in more frequent and stronger floods and droughts. The disparity between water availability and demand is growing, exacerbating water insecurity in Bolivia. This imbalance serves as a clear warning sign of water insecurity, which, if unaddressed, could impact economic stability and development.

Recognizing the need to enhance water resilience for ongoing national development and to protect previous achievements, the focus on water resilience has become a key priority on Bolivia's political and national agenda. This commitment aligns with strategies outlined in PDES aimed at guiding the country's economic priorities. In this context, Bolivia has seen the emergence of several policies, plans, and programs, with the PNC standing out as one of the most significant. Framed as a critical enabler of IWRM, the PNC assumes a central role in the pursuit of water security. It includes strategically designed implementation components with notable socio-economic implications.

Multiple studies have deeply analyzed the water governance contexts in Bolivia (Llanova, 2020; Saavedra, 2021; CIF, 2023), and came up with very important and spot-on recommendations for improvement. The following lines present a compilation of some of the most relevant in the context of enhancing water resilience for economic resilience:

- **Adaptation and mitigation tradeoffs**: A skillful assessment of the risks and opportunities for adaptation related to domestic/foreign mitigation strategies is required to fairly distribute associated costs and benefits. This includes those associated with the anticipated increase in demand for minerals and other natural resources, including lithium and biofuels, which could add significant pressure on water systems as the low-carbon transition accelerates globally.
- **Data**: Improving access to hydrometeorological data and climate information systems, extending from national to local levels, is crucial for informed water resource allocation and community engagement in water governance. High-quality data access is central to effective water resource management, as the information gap hinders management. While water governance initiatives enhance data collection and interpretation at higher levels, including national and departmental, there is room to expand such efforts to municipal levels. A beneficial next step involves supporting the creation of climate services that make hydrometeorological data more accessible and practical for community members. This approach would also focus on capacity building at the municipal and community tiers, fostering comprehensive understanding and sustainable water management.
- **Intersectoral collaboration**: In water project implementation, the primary

partners are typically water and environmental policy institutions at national and subnational levels. However, involvement from other sectoral ministries and agencies is common to facilitate agreements among different water users. Establishing inter-ministerial coordination could improve project efficiency. This emphasizes the requirement for broader intersectoral collaboration beyond water and the environment, essential for effective IWRM as well as planning and execution of just transition measures.

- **Political economy**: Addressing the intricate political dynamics of water governance, such as tensions between upstream and downstream users, is key for initiative feasibility and sustainability. Projects should recognize diverse decision-making influences and include both influential and disadvantaged groups as direct beneficiaries. Ensuring effective participation of disadvantaged groups in planning and decision-making, rather than just as recipients of compensation, is essential. Attention is also needed on potential conflicts between global decarbonization driving mining growth and communities' climate resilience needs in Bolivia.
- **Circular economy**: Incorporating circular economy principles into the water and environmental policy and related sectors is vital. This involves promoting these principles in public services and water initiatives through clear policies, financial incentives, technical support, and public awareness. Moreover, revisiting the existing regulations is necessary to facilitate circular economy projects. This review should address wastewater reuse, biosolid generation, and energy recovery from transformed methane to biogas or its use as an energy source. Importantly, this regulatory assessment should extend beyond water, considering its impact on energy, healthcare, and the environment.

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California Investing Now to Forestall Climate Change's Worst Water Impacts

by Felicia Marcus[1]

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Key Messages

- The development of the Southwestern United States has been based upon the development of public works infrastructure that captures, stores, and brings water hundreds of miles to agricultural and urban centers. That development has yielded enormous economic value, often at the cost of the ecosystems of origin, in both agricultural output and a vibrant social and economically prosperous urban sector. That development has happened through a sense of optimism about water supplies that has been greater than the geophysical record would suggest. Nonetheless, the region has thrived and parts of it have a history of greater and greater efficiency, recycling, and conservation to stretch increasingly scarce urban water sources.
- The people and economies of the Southwest US are at greater risk due to climate change, which will make the variability of the region even more unpredictable and likely result in more frequent and drier dry times punctuated by extreme wet events.
- Urban and agricultural areas can adapt and have been adapting

through greater implementation of efficiency measures. These include conservation, recycling, stormwater capture, and desalination (in some cases) in the urban sector, and efficiency, managed aquifer recharge, and sustainable groundwater management in the agricultural sector. The State of California, in particular, has placed great emphasis and investment on preparing for a more climate-impacted future as have some urban areas in other states, such as the Las Vegas, Nevada area.

- The scale and pace of adaptation must accelerate to meet the challenge, with a need for greater investment now to prevent greater economic pain later. Greater investment in economic analysis of the cost of future disruption needs to be integrated into current public policy discourse to convey the urgency of and potential for adaptation prior to disasters.
- There is an urgent need for better economic assessment of and support for multiple benefit projects that can include nature-based solutions (NBS). NBS can be more resilient in the face of climate change and multiple benefit projects are more likely to gain public approval for the investments necessary for them to come to fruition.

Introduction and Context

What's at stake in the West given climate change's impact on water resources? Everything.

The story of the development of the western United States, and particularly the Southwest, is the story of water development. The western United States has more variable hydrology than the eastern US, with a generally Mediterranean climate as well as desert climate. It is considerably drier than the eastern United States, with the dividing line being seen as roughly the 100th meridian. California's weather is even more variable even than the rest of the West. For California, "The wettest year on record is 1983, which produced 71.9 MAF of runoff; the driest year on record, 1977, produced only 5.6 MAF" (Maven's Notebook, 2013).

Because of its relative dryness and variability, the large-scale settlement of the West required the use of storage and conveyance projects to both store water across multiple seasons or years, and to convey it broadly across the region. European settlement of the West and subsequent population growth therefore necessitated massive infrastructure projects that capture, store, and move water long distances to metropolitan and agricultural areas.

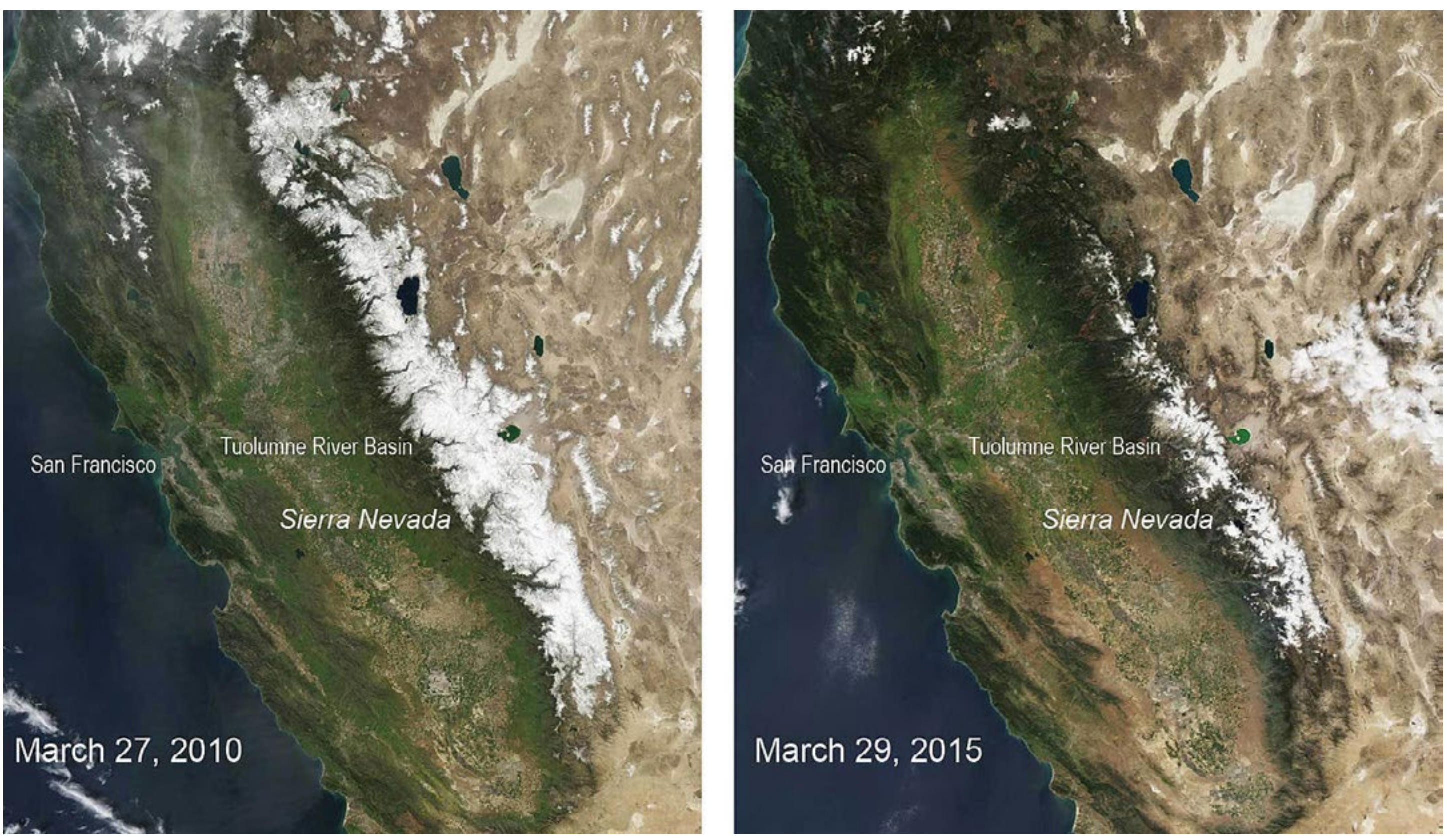
Even in the relatively drier western United States, some places such as California and the Rocky Mountain states have mountains that accumulate heavy snowpack. Snowpack is the Southwest's greatest single storage resource, far bigger in scale than built infrastructure. That snowpack holds precipitation in a form of storage, which then melts out during the spring and summer to replenish reservoirs, rivers and streams, and groundwater basins at a pace that is more able to be absorbed than in winter deluges. With a very slight temperature rise Celsius, snow melts earlier, or falls as rain in the first instance, leading to greater flooding in the spring, and far less snowpack remaining to replenish the built reservoirs, natural water courses, and refill groundwater basins (Whyte, 2017).

Estimates of climate change's impact on water resources during the next two to

California's major rivers and facilities. Source: California Department of Water Resources three decades range from a 10 percent reduction in total water available by 2040 in California (CNRA, 2022) to 20 percent or more reduction by mid-century (Udall & Overpeck, 2017). Those averages, however, mask the impact of the variability of each year, with years of drought bringing far greater reduction and pain, and years of extreme flooding expected to bring perhaps less frequent, but even greater destruction to people, property, and the environment.

With increased temperatures, we also see less precipitation, whether rain or snow, reaching the ground as it evaporates while falling. And, even when it falls, it can be absorbed into the drier ground or foliage, not reach the ground before turning to gas, or even evaporate back out into the atmosphere (Fassnacht, 2021). We are already seeing dramatic differences in the amount of runoff reaching reservoirs from the same amount of precipitation, with California experiencing a 740 MCM shortfall in 2021 from what was expected from past experience (Abatzoglou et al., 2021).

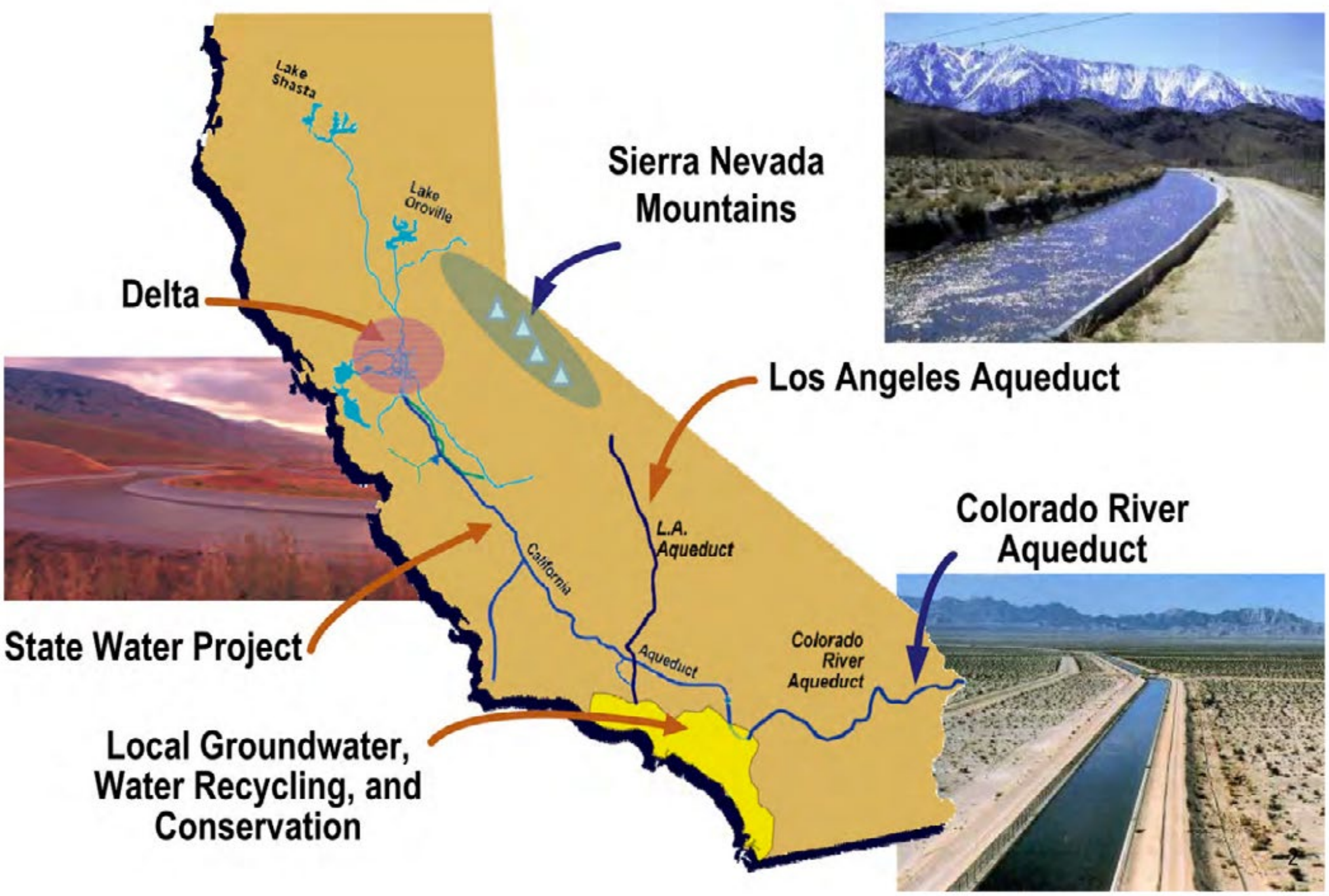
Groundwater is an abundant resource in some places, non-existent or unreachable in others, and is an imperiled resource in many places, as users — primarily agricultural users — have pumped groundwater to make up for years of surface water shortage without cutting back on production, or have increased production. This “overdraft,” estimated to be an average of 2.47 MCM per year in California’s Central Valley, has led to land sinkage, infrastructure crumbling, and a loss of storage space for the future (WEF, n.d.). Even more concerning, it represents current populations and economies pursuing economic gain to the detriment of future generations.



Comparison of snow cover from NASA’s Aqua satellite. Source: NASA/Modis

Why Does This Matter?

Whole economies and communities developed based upon flawed expectations of what the built infrastructure and natural environment would provide. That expectation was based more upon hopes and dreams at times than upon a clear-eyed view of the historical or geophysical record. For example, in the Colorado River Basin, in the late nineteenth century, explorer John Wesley Powell was sent to explore the river basin and report on prospects for development. He wrote that the hydrological variability would be dramatic and that future large-scale development expectations, particularly for agriculture, should be scaled back. His advice was not taken. Projects were built and massive agricultural and urban development have ensued, quite successfully for well over 100 years. However, the 40 million people in seven states, two nations, and 30 tribal indigenous groups that rely on the river and its tributaries watched in horror recently as the system came near the point where its reservoirs could no longer generate hydroelectricity or water after 23 years of increasing aridification and drought. The federal government threatened historic cutbacks. The potential economic impact of disruption of this vast amount of water has captured headlines. Estimates of economic reliance on the Colorado River have reached US$ 1.4 trillion at risk of disruption (Oshrin, 2015). While avoided by an abundant year of precipitation and snow in the winter of 2022–2023, the region is embarking on



Southern California water sources. Source: LADWP negotiations for a new operations regime in 2026 when the current agreements are due to end (James & Smith, 2023).

Similarly, Central Valley agriculture and the economic and social boom of Southern California were based upon projects built in the middle of the last century that captured rain, and then melting snowpack, and conveyed it from the Sierra Nevada mountains to agricultural and urban areas hundreds of miles away; for Central Valley agriculture, that means the Western Sierras, while for Southern California, it is a mix of Eastern and Western Sierras and the Colorado River.

The economic impact of disruption of this vast amount of water is considerable. For example, an economic assessment of the 2015 drought found a US$ 2.7 billion impact for agriculture, but acknowledged that the impact varied considerably by region (Howitt et al., 2017). For context, the average agricultural income as of 2019 was approximately US$ 50 billion (CDFA, 2020).

The City of Los Angeles' Department of Water and Power (LADWP) has recently commissioned a "resilience study" being conducted by researchers at the University of Texas and Oxford University (formerly at UCLA) to estimate the true economic cost of disruption of imported water supplies upon which the city relies currently for the lion's share of its water use. This assessment will give a more realistic comparative estimate to illustrate the value of the billions of dollars that the city plans to spend to recycle 100 percent of the wastewater now being discharged to the Pacific Ocean from its Hyperion Water Reclamation Plant. This comparison is more relevant to the city's real-world situation than comparing the cost of recycled water to the current or even future estimated cost of imported water (which is the usual comparison used). It doesn't take a Nobel-prize winning scientist to understand that if the water isn't there, the economic cost to the community is vastly higher than the relative cost differential of imported water vs. recycled water, stormwater capture, or desalination.

This is why, as described in more detail below, the City of Los Angeles and the Metropolitan Water District of Southern California are both in the process of planning, piloting, and developing what will be the two largest potable water reuse projects in the world, eclipsing even the current largest recycled water facility operated by the Orange County Water District. Price tags for each project singly range into the multiple billion dollars. The County of Los Angeles and its 89 cities have also risen to the challenge through public passage of a US$ 300 million/ year measure to construct multi-benefit projects for flood control, water supply, water quality, and urban greening to deal with both climate and water challenges.

Fortunately, in much of the western US rimmed with mountains, there will still be years with snowpack, albeit fewer and many with less bounty. Estimates are for what has been termed "weather whiplash," with more frequent and drier dries punctuated with dramatic wet periods, such as what California is experiencing in the winter of 2023–2024. This is good compared to those areas of the world that will simply get drier. However, capturing that water, when not in the form of snow, will be impossible at the scale and magnitude in which it will arrive. That said, as described below, with investment and application of new technologies and organized capture, more of it can be captured and stored underground to better help withstand the coming dries.

California as a Case Study in Taking the Long View

California is the fifth largest economy in the world (CBS, 2018), known for its frequent leadership in environmental pollutant regulation. While many think about California's climate leadership in terms of regulations to reduce climate change-inducing emissions and its decades' long leadership in energy efficiency and promoting clean energy, California has also made the shift towards thinking about climate adaptation, particularly with regards to water. What follows are some of the big, and often expensive, policy investments that the state is taking to forestall even greater economic pain in the future.

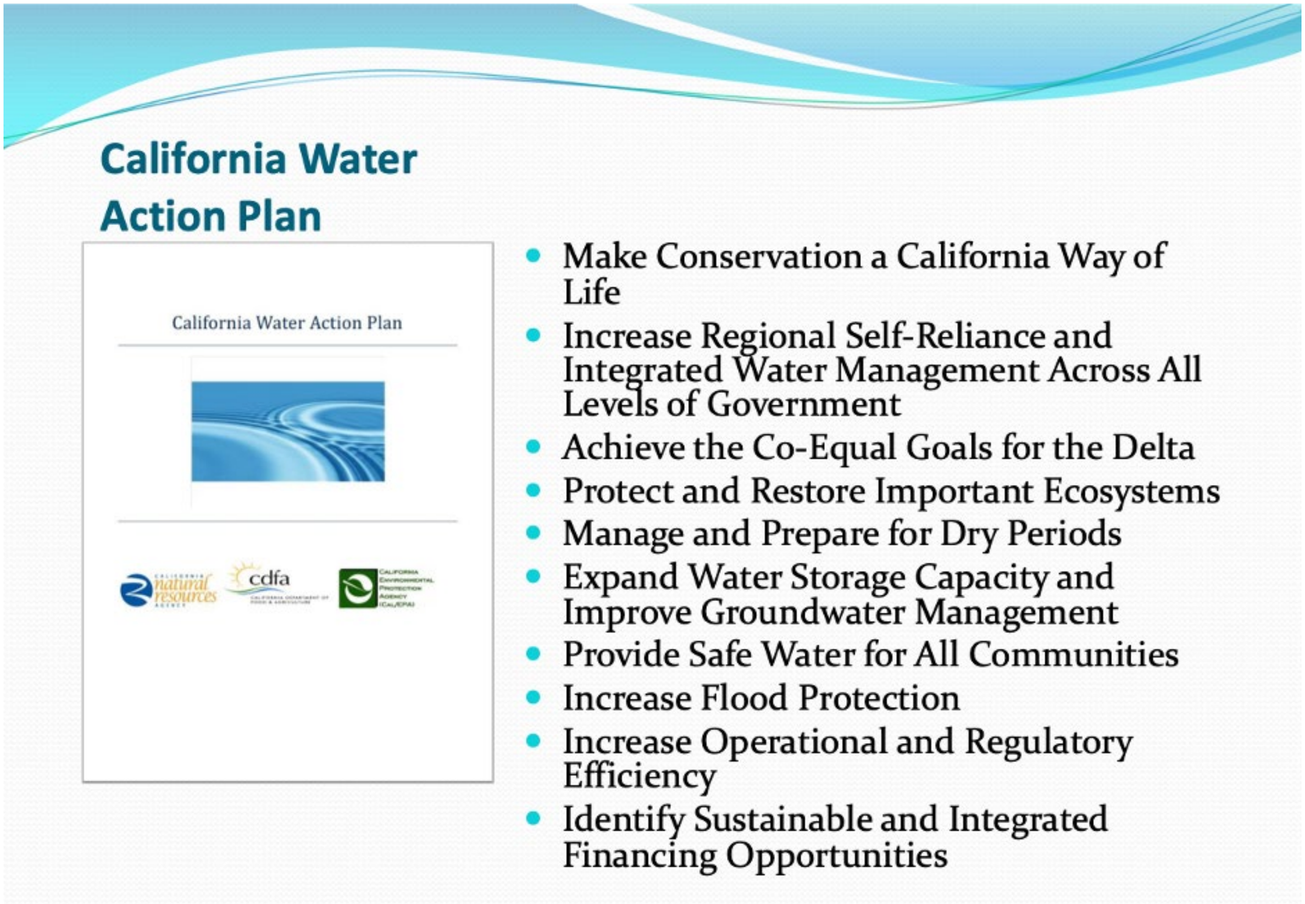
During the administration of Governor Jerry Brown (2011–2019), the administration developed an "all-of-the above" California Water Action Plan (CNRA, 2014) motivated specifically to deal with the impacts that climate change would have on California's water system and to invest and focus on measures that would protect the state against the ravages to come. The Water Action Plan included a suite of ten measures, with "Conservation as a California Way of Life" first and foremost as the most cost-effective and timely tool to reduce the state's vulnerability. The plan also included a call to invest in more regional resilience through efforts like stormwater capture and water recycling and desalination in the appropriate circumstances[1]. Other big policy objectives included managing groundwater so as to be able to use the state's groundwater basins to store water more effectively to offset the loss of projected snowpack, delivering safe drinking water to all Californians to make good on the state's "Human Right to Water" statute, preparing for floods and droughts, protecting the state's ecosystems, and other measures. The plan was used to develop state funding propositions put before the voters which were successful in yielding US$ 12 billion for an array of programs (Rosser & Chappelle, 2021). The plan also led to significant actions to move forward on the "all-of-the-above" strategy it laid out.

The subsequent administration, that of Governor Gavin Newsom, adopted and built upon the strategy to continue and accelerate efforts to adapt through a "Water Resilience Portfolio" and other subsequent policy statements (CNRA, 2020). With a robust economy, the Newsom Administration was able to include many more billions of dollars in general funding for water adaptation efforts in 2020 and 2021, and the state legislature is currently considering another multi-billion bond measure for the 2024 ballot which will include water elements. Some of the many programs that came out of these administrations' efforts are described below along with locally driven adaptation by communities that recognize the need to invest now to preserve their tomorrow.

Conservation and Efficiency: Emergency Response to Ongoing "Way of Life"

During the historic California drought of 2013–17, the administration accelerated its call to make "conservation a California way of life" through mandating

[1] Desalination is currently an expensive, energy intensive, and environmentally damaging approach compared to conservation, water recycling, and stormwater capture in communities that have groundwater basins in which to store recycled water or stormwater. However, there are communities without groundwater basins and without certain and consistent access to imported water for whom a modest amount of desalination is worth the cost (e.g., San Diego, Santa Barbara). This report does not take a positive or negative view of desalination, but simply notes that it is not the most economic or environmental choice in most places, although it remains a viable option for some communities, particularly those without sizable groundwater basins in which to store recycled water or captured stormwater.



Summary of the California Water Action Plan. Source: Felicia Marcus

unprecedented urban water conservation rules requiring an average of 25 percent reductions in water use. The public rose to the occasion, saving 24 percent in short order through a combination of behavioral change, letting lawns go brown, and when affordable, changing out their water-thirsty lawns for more water tolerant landscaping. The water agency targets (tiered according to the magnitude of per capita water use) were accompanied by mandatory use restrictions, such as not using hoses to clean sidewalks and driveways, bans on fountains without recirculation pumps, bans on watering highway medians, and other measures.

Local water agencies, such as the wholesale Metropolitan Water District of Southern California (Metropolitan), put out hundreds of millions of dollars in lawn and appliance transition rebates which were augmented by local water retailers. The purpose of the rebates was not a dollar per gallon or per acre foot calculation in the short term, but was to accomplish a paradigm shift that would lead to savings in the long run as the work "inspired" action (see, for example, Metropolitan, 2022). Other state legislative and regulatory efforts started and have continued even after the emergency regulations were rescinded, including outdoor landscaping standards for new developments, water efficiency regulations for all urban water suppliers that will be based upon an average per capita indoor use plus a climate calibrated outdoor budget across their service area, and rules for a standard amount of leakage allowed in a system.

This emergency and long-term state and local action came on a foundation of decades of conservation and efficiency improvements that have allowed communities in Southern California to grow considerably while using 38 percent less potable water per capita since 1990 (Metropolitan, 2022), proving that one can decouple water use from economic growth through efficiency and other measures.

Water Recycling and Stormwater Capture Take Off

The Los Angeles region's imported supplies are threatened by disruption of several kinds, including climate change, earthquakes or other physical disruption, and increasing environmental regulation to protect the ecosystems from which their water is diverted. Of these three, climate change poses the most substantial risk, as both the Sierra system (the State Water Project) and the Colorado River system are projected to see increasingly frequent and drier dry years. This challenge is exacerbated by climate change, as even modest temperature rise results in precipitation that does more falling as rain rather than snow, depriving both systems of their single largest source of storage over multiple years. As a result, in addition to the world leading recycled water/groundwater recharge work of the nearby Orange County Water District (130 million gallons per day (MGD)), the Los Angeles region's utilities are accelerating their plans to both capture stormwater and vastly expand their water recycling capacity. The two will each become in turn the largest recycled water projects in the world.

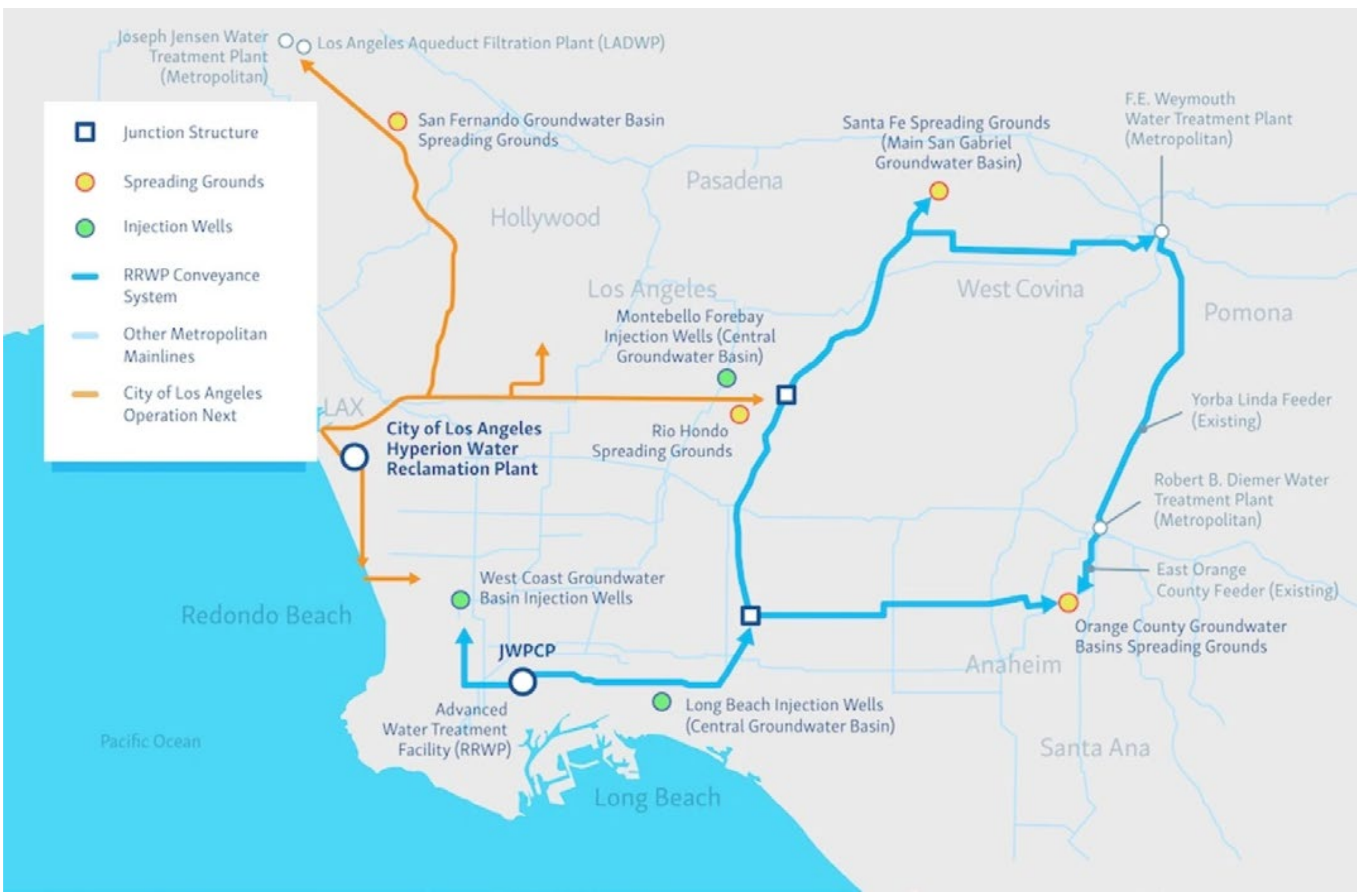
The City of Los Angeles (City of LA) is home to 4 million people and is served by its Los Angeles Department of Water and Power (LADWP) that provides water and power to the City's residents and by the Department of Public Works' Bureau of Sanitation (LASan) which operates the City's wastewater programs. Metropolitan provides wholesale water supplies to Southern California's 19 million residents. The Los Angeles County Sanitation Districts (LACSD) provide wastewater services to 24 districts serving the 10 million residents of Los Angeles County. The Los Angeles County Public Works Department services the 10 million residents as well, providing flood control, groundwater recharge, and other services. They are also in charge of managing the County's stormwater management permits.

The City of LA's two-part reuse program, "Operation NEXT" and "Hyperion 2035," relies on the close cooperation between LASan and LADWP. LASan's role is to upgrade the treatment provided at the Hyperion plant to produce recycled water for indirect and/or direct potable reuse applications. Their part of the Hyperion 2035 program has commenced with the design of a 1.5 MGD pilot facility demonstrating the suitability of membrane bioreactors, reverse osmosis, ultraviolet disinfection, and advanced oxidation. Currently, the program's goal is to produce up to 230 MGD of advanced treated water suitable for groundwater replenishment. Following treatment at the plant, LADWP (Operation NEXT) will take over responsibility for conveying the water for aquifer storage and higher levels of treatment (LADWP, n.d.) with the aim of eventually treating water to direct potable reuse standards at the City's drinking water treatment facilities.

Just as ambitious, Metropolitan and LACSD's Pure Water Project is anticipated to provide an additional 150 MGD of recycled water for groundwater recharge (via both spreading and injection), industrial reuse, and eventually direct potable reuse. The recycled water will come from Metropolitan's partner agency, LACSD, which has operated its Joint Water Pollution Control Plant for nearly a century. To produce water suitable for potable reuse, LACSD will add advanced treatment and disinfection for 150 MGD of effluent that Metropolitan would then convey to four large groundwater basins throughout Los Angeles and Orange Counties (Metropolitan, 2021). Like Operation NEXT, future plans call for conveyance and more advanced treatment for integration directly into Metropolitan's considerable drinking water treatment and storage systems.

The two projects are also evaluating how they can link together across the greater region to produce a virtual water grid across over 60 miles to achieve greater resilience. In addition, the Metropolitan/LACSD Pure Water project has agreements as far away as Las Vegas, Nevada and Arizona to exchange access to Metropolitan's Colorado River supplies for financial participation in the recycled water project. Metropolitan has also invested heavily in other infrastructure projects, including totalling over $2 billion in two large scale projects to provide offstream storage and the ability to move water between its Colorado River and Sierra supplies. Together the projects can store more water, improve water quality, and serve more customers: Diamond Valley Lake Reservoir (Metropolitan, 2019) and the Inland Feeder Line (Metropolitan, 2007).

In addition to years of conservation and the expansion of water recycling, the region has also grown its stormwater capture vision and capacity. The City passed a measure that raised US$ 500 million and has constructed many inspiring multi-benefit stormwater treatment and capture projects that have also generated valuable green spaces



Potential future integration of Los Angeles city and Metropolitan/LACSD potable reuse programs. Source: Metropolitan Water District of Southern California through a combination of parkland, wetlands restoration or creation, and retrofit of neighborhoods with cisterns, berms, swales, etc. (Planning Report, 2018). Building upon this success, Los Angeles County developed and passed a US$ 300 million/year funding measure to implement a massive effort to build multi-benefit projects to increase urban greening, protect water quality in the area's receiving waters, provide flood control, and capture stormwater for water supply replenishment. These measures were able to gain agency and voter support because of their multi-benefit promise of delivering on water security while also providing water quality and urban greening projects and some additional flood control.

The State of California has played a role in helping to encourage both the expansion of water recycling and of stormwater capture as part of its Water Action Plan work through funding (billions in grants and low-interest loans) and through regulatory measures that encourage certainty in water recycling standards and incentivize multi-benefit approaches to stormwater capture and treatment through nature-based solutions (NBS) (Marcus et al., 2020; Rosenblum et al., 2022). Over the next two decades, the region will transform underground as it builds out its water recycling system, while above ground the region will transform visibly with multi-benefit greening projects that will also enhance the region's water security and demonstrate the power of NBS.

Groundwater Management: SGMA, MAR, and Land Repurposing

The largest policy change to come from the Water Action Plan was the 2014 passage of the state's historic Sustainable Groundwater Management Act (SGMA) (Leahy, 2015). Because of the looming loss of snowpack, and therefore the loss of California's single largest source of storage (30 percent on average), then-Governor Brown recognized that the only thing large enough to compensate for that loss of storage was the state's long-overdrafted aquifers. Overdrafting had led to massive subsidence, causing infrastructure to crumble and valuable storage space to be lost, in addition to threatening the future viability of farming in many regions. The only way to stop the overdrafting and reverse the processes of subsidence and depletion was to develop a management scheme. SGMA requires local coalitions of overlying landowners and public officials to develop plans, through a combination of demand management and focused recharge efforts during the wet season, that will get each basin to a sustainable level over a 20-year timeframe. The 20-year timeframe was chosen to allow for a less economically and socially jarring transition to meet the expected consequences of climate change. Estimates are that between 500,000 to 1,000,000 acres of farmland in the San Joaquin Valley (out of five million acres) will go out of production during this time in order to assure a long-term future for farming in the region (Hanak et al., 2019).

SGMA has spawned a massive effort on the part of localities to develop plans to measure, allocate, and restore depleted aquifers. The planning efforts are ongoing. Groundwater Sustainability Agencies (GSA) have been formed. Plans have been submitted and assessed, often found lacking and in many cases fixed. Others have been referred for enforcement action. A combination of technological advances and state support have been applied to find ways to recharge basins more efficiently and effectively to promote what is known as Managed Aquifer Recharge (MAR) (CDWR, n.d.). To aid in that transition, the state is employing advanced technology to map the underground of a vast area of the Central Valley of California to help local agencies find the best places to recharge basins and the best places to retrieve the water (Simon, 2023). The state has also put out millions of dollars in grants to local agencies to help with planning and implementation of projects and has a special "land repurposing" program to help fund collaborative projects to help transition farmland to lower water use purposes, such as solar development, lower water use crops, or groundwater recharge basins, some of which are also being adapted for ecological restoration (Moore, 2022; CDoC, 2023). The costs to farmers and the state to make this shift are enormous but are being taken to avoid the painful alternative of massive fallowing during the disastrous future to come if they do not begin to act now. To paraphrase the CEO of Driscoll's, Miles Reiter, at the signing ceremony for SGMA: This will be the hardest thing many of us ever do, but it is necessary if we want our children and grandchildren to be able to farm.

The Bigger, Longer Lifts: Nature-based Solutions

California has also taken a longer term view of water security and sustainability by accelerating efforts to incorporate NBS into its climate, biodiversity, public security, and water agendas because of the multiple benefits that those efforts deliver. Efforts include billions of dollars from the state's California Climate Investments fund (funded by proceeds from the state's "cap-and-trade" climate regulatory program) and general fund to implement ecologically-based forest restoration. The effort is designed to reduce the risk of outsized conflagrations due to the overgrowth of forests. These unnaturally dense forests differ dramatically from California's historical forests, where trees were spaced apart and wildfires due to lightning strikes commonly raced through the low grassland leaving the larger trees unscathed. Through well-intended but overzealous wildfire suppression and corporate forest products companies' attempts to maximize production, the current status of many California forests leads to a density of underbrush (known as fuel ladders) which causes hotter fires to rage higher and consume larger trees that would ordinarily survive. These conflagrations send massive carbon plumes into the atmosphere, and send sediment and other contaminants downstream. Properly thinning forests can reduce the risk to life and limb, reduce carbon emissions and protect the larger trees that sequester more carbon, and can yield water benefits of reducing contaminants, while allowing for greater snowpack deposition and duration on the ground. When combined with meadow restoration, forest restoration can also create fire buffers, wildlife refugia, and some slowing of the flow downstream to make up for the snowpack lost to temperature rise (Marcus, 2022). The state has also invested millions into meadow restoration and healthy soils agricultural practices, and has incorporated such practices into its climate reduction plans and other plans (Marcus, 2022).

Also at the state level, there are growing efforts to integrate more natural solutions into water planning, again for multiple benefits, but particularly for flood protection. For example, the state's Central Valley Flood Protection Plan promotes the use of floodplain setbacks rather than higher levee walls to allow flood force to dissipate through spreading across land, which also can give ecological benefits and recharge groundwater basins (Powell, 2023). The Dos Rios project implemented by River Partners provides an example of the type of project that is gaining state support and investment (recontouring land at the confluence of the Tuolumne and San Joaquin Rivers to allow for greater inundation and dissipation of flows to benefit ecological restoration and lessen flood risk downstream). The project received US$ 15 million in state funding, and has recently been designated as an official state park (Bartlett, 2022).

NBS are also gaining traction and significant investment in urban settings. In addition to the Los Angeles County Stormwater example mentioned above (US$ 300 million for multi-benefit stormwater projects for flood control, green space, groundwater recharge, and water quality improvements), the San Francisco Bay Area has embarked upon a truly breathtaking endeavor (both from an engineering and economic perspective) to employ NBS to adapt to climate change. Two-thirds

San Francisco Bay shoreline areas potentially exposed to sea-level rise. Map is for informational purposes only. Source: San Francisco Bay Conservation and Development Commission (BCDC) of the estimated cost of sea-level rise in California is expected in San Francisco Bay, which is a heavily urbanized area surrounding one of the most picturesque estuaries on the US West Coast. To combat this challenge, the nine counties and 100 cities around the bay came together to pass a US$ 500 million measure to use horizontal levees to deal with sea level rise rather than have a war of piecemeal seawalls which would lead to greater wave force on each other (Meadows, 2021). The Bay Area decided to spend billions over the coming decades to save many more billions in the future (MTC, ABAG, & BCDC, 2023a). This approach also has the multiple benefit value of providing greenspace and ecological value in addition to buffering sea-level rise (MTC, ABAG, & BCDC, 2023a; MTC, ABAG, & BCDC, 2023b).

To prepare and adapt to climate change using NBS will take an attitude of multiple benefit thinking on the part of policy-makers. To assist them, there is a tremendous need for multi-benefit guidance for evaluating the cost-benefits of working across single silos. The Pacific Institute's CEO Water Mandate is doing important work with The Nature Conservancy and private sector partners to develop tools for better recognizing the true benefits of projects that can provide benefits for both climate mitigation and adaptation including water resources and other benefits (CEO Water Mandate, n.d.; Shiao et al., 2020). They have also developed a standardized method to account for "stacked water and carbon benefits and identify wider co-benefits of NBS for watersheds" (Brill, 2022). Current stages of work look to consider benefit forecasting (i.e., how different benefits accrue proportionately over time and across spatial scales across multiple habitat and intervention types) and benefit valuation (i.e., cost-benefit and return on investment estimates) (Brill, 2022).

Conclusion

Adaptation requires long-term thinking, planning, and implementation. California and other western states are acting to prepare for a future of greater extremes, such as more frequent and drier drought periods punctuated by extreme precipitation that is more likely to fall as rain rather than snow. Greater dry spells, greater flooding potential, and the loss of valuable snowpack as a timing delay for water flow from mountaintop to rivers and streams, agricultural lands, and groundwater basins are all expected.

Adaptation actions are taking many forms, a few of which are described above, to deal with the crises to come based upon common sense and an awareness that action must be taken on multiple fronts. The momentum is there, but an accelerated pace is needed to meet the moment. A variety of economic tools and perspectives are needed to help policy-makers and the public make the investments now that are needed to forestall even greater costs, let alone greater impacts, to come if action is delayed. Action now will be expensive, but less expensive than doing nothing and having to recover from disasters that could have been prevented. Making the case for these investments, which cross traditional silos of geography, organizational institutions, and disciplines is complex. Better guidelines and approaches to valuing costs and benefits will help policy-makers and the public choose to act and choose investments wisely.

Some recommendations and lessons:

- The scale and pace of climate adaptation in the water arena must accelerate to meet the challenge, with a need for greater investment now to prevent greater economic disruption later.

- Greater investment in economic analysis of the cost of future economic harm due to disruption of water systems, such as those dependent upon imported water or subject to natural disasters, needs to be integrated into current public policy discourse to convey the urgency of the need to invest now to prevent disastrous and avoidable economic consequences down the road.
- Tools for basic economic assessment of and support for multiple benefit projects are needed, especially for those like urban stormwater capture projects that can include NBS. NBS can be more resilient in the face of climate change, and multiple benefit projects such as those utilizing NBS are more likely to gain public approval for the investments necessary for them to come to fruition.
- Sharing an overall picture of the varied measures needed for a sustainable water management system helps to move people to support action on a variety of measures, as a broader public can see their needs being met.
- Bold vision, coupled with data and a willingness to make the case to a variety of stakeholders is essential to support the big projects and changes necessary to meet the climate challenge (e.g., groundwater management, conservation, large scale measures like recycled water and stormwater capture projects, forest restoration, and floodplain management).
- The public will act and support funding or their own efforts to conserve, for example, if information is shared with them transparently and consistently (e.g., supporting bond measures, rising to the occasion, and conserving water).

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Water Resilience for Santiago de Chile

by Gustavo Migues[1], Cristian Schwerter[1], and Ivan Yarur Sairafi[1]

[1] Veolia

Key Messages

- Chile's economic resilience is facing a critical challenge from water scarcity, which has been intensified by growing vulnerability to drought. Water demand has surged due to a period of robust economic growth and the country's heavy reliance on water-intensive industries. The mining sector alone was expected to increase its demand for water by 45 percent in 2020.
- Social resilience is also threatened by droughts. In 2021, the fourth driest year in Chile, more than 50 percent of the population, or 19 million people, resided in an area that was severely affected by water scarcity.
- An expected increase of 3 °C in temperature due to climate change is predicted to cause several impacts, including droughts, turbidity events, and reduced water availability from glaciers.
- Government reforms implemented in 1990 have allowed private operators to enter the market and facilitated financing of over US$ 2 billion for investments in wastewater treatment plants. Currently, the Chilean water production and reuse market is fully privatized.
- Privatization has enhanced the market's competitiveness, overall

water quality, and contributed to cost reduction as well as continuity to the point where the country now has 100 percent coverage in both drinking water and sanitation. For example, Aguas Andinas is the largest water and sewage utility in Chile that serves around 40 percent of the Chilean population.

- Chile has achieved 100 percent treatment of its urban wastewater, which is an important step towards sustainability. However, there is an opportunity to further enhance economic resilience by transforming wastewater into a productive resource which is currently not utilized.
- The private sector's role in promoting water resilience goes beyond providing water-related services. It includes assuming responsibility and leadership for responsible investment that prioritizes sustainability and environmental protection. Also, improving the efficiency of water resources and communicating responsible use protocols to their consumers.

The Climate Change Challenge

Chile, a South American nation, has emerged as one of the most prosperous in the region. Its economic strength and solid institutions have successfully weathered three major shocks: namely social unrest in 2019, the COVID-19 pandemic beginning in 2020, and the 2022 Russian-Ukrainian war. In spite of these shocks, its economy actually experienced growth by 11.7 percent in 2022. According to the World Bank (2021), Chile has one of the swiftest recoveries worldwide despite the remarkable contractions it witnessed — particularly following the social unrest.

Nevertheless, the Chilean economy remains challenged by high inflation, widespread inequalities, population growth, informal employment (affecting one-third of the workforce), and environmental challenges. The Chilean Ministry of the Environment states that the country is highly vulnerable to climate change. Its effects are already being felt in the national territory. Climate projections for Chile show that the main effects are a rise in temperature and a decrease in precipitation. Thus, an increase in the frequency of extreme events such as droughts and river and coastal floods is highly likely.

Chile is ranked as the 10th most water-risk-prone country out of 142 countries (4th among OECD nations, trailing only the US, Mexico, and Australia) (OECD, 2017). The northern part of the country is arid and semi-arid and is projected to see its temperatures increase in the next century, while experiencing more frequent warm storms that produce mudslides and episodes of high turbidity in the basin of the rivers. This will have negative impacts on its main productive activity: mining. The most affected area of the country will probably be the central zone, where the capital city Santiago is located. In the coming decades, precipitation reductions of around 20 percent and temperature increases of 3 °C are expected in this area. This will have important effects on the most densely populated area of the country — an area that also includes a dense concentration of its agriculture, forestry industry, and hydroelectric power. Some of the effects in drinking water production are described below:

- **Drought**: Central Chile is suffering two decades of uninterrupted drought. As a result, freshwater sources have experienced a continuous decline. At present, the

Metropolitan Region has a worrisome structural water deficit (gap between available water resources and the real needs of the area) of up to 250 cubic hectometers under certain hydrological conditions. This is a situation that will continue over time and could even worsen. For this reason, it is fundamental to increase efficiency in the use of water resources and adding more water resources to the productive matrix.

- **Turbidity events**: Increased turbidity in the upper basin of the rivers has a significant impact on drinking water production and has a high probability of affecting customer supply. Turbidity events are classified into four groups: 1) winter rainfall events, 2) summer rainfall events, 3) snowmelt, and 4) extreme rainfall events (atmospheric rivers). The snowmelt event in particular is associated with the increase in temperature without the occurrence of precipitation that causes increased river flow, which in turn causes increased sedimentation.
- **Reduction in the availability of water from glaciers**: Glaciers undergo changes in response to variations in other components such as climate, volcanic activity, and human action. These modifications are mainly evident in their geometry, volume, thickness, mass balance, and their contribution of liquid water to the ecosystem. Due to the more severe effects of climate change and the prolongation of the drought affecting the central zone, glaciers in the Metropolitan Region are losing volume at an accelerated rate, among other alarming changes. In central Chile, 65.4 percent of the glacier surface is located below 4,000 m above sea level. When the temperature in the valley reaches 30 °C, at that altitude there is a positive temperature of about 10 °C shortly after midday — enough to melt several meters of ice at the end of a warm summer. But glaciers are not only melting faster due to warming; they are also losing more ice by sublimation due to increasingly dry conditions, and the higher elevations fail to recharge with sufficient snow during the winter. Initially, as it melts at a faster rate, a glacier contributes more water to the basin, but only until it reaches a critical point: when it begins to decrease its water yield due to its smaller size. This puts the water supply for the city of Santiago at risk, especially in summer, when 70 percent comes from glaciers.

The Threat of Water Supply to Chile's Economic and Social Resilience amidst Climate Change Challenges

Chile's economic resilience is facing a critical challenge from water scarcity, which is being intensified by growing vulnerability to drought. In the past few decades, Chile has experienced a surge in water demand, largely due to a period of robust economic growth and the country's heavy reliance on water-intensive industries such as mining, agriculture, forestry, and fish farming. For instance, Chilean Copper Corporation reported that the mining sector alone is expected to increase its demand for water by 45 percent in 2020, while forecasts indicate that agriculture will require an additional 4 km^3 over the next 40 years (COCHILCO, 2009).

Water challenges have direct or indirect repercussions on most of the country's productive activities. In 2020, the reduction in copper production was primarily caused by supply-side issues such as water restrictions. This has diminished Chile's exports.

Social resilience is also threatened by droughts. For example, 2021 was the fourth driest year in Chilean history. More than 50 percent of the population, or 19 million people, resided in an area that was severely affected by water scarcity. In fact, according to the study "De Estructuras a Servicios" sponsored by the Inter-American Development Bank (IDB), Chile is the country with the highest proportion of its population living in basins with water stress and will continue to be in the next decades.

Certainly, Chile's economic and social resilience relies significantly on fulfilling the water requirements of its water-intensive industries and residents.

Private Sector as a Key Enabler in the Chilean Water Production and Reuse Market

During the 1980s, Chile underwent a range of free-market economic changes, one of which was the transfer of control over the country's water and sanitation services from the government to private corporations. This means that it is now the responsibility of private entities to deliver these vital services to the public.

Privatization has been very beneficial to the water sector in Chile. One of the benefits of privatization is that it can lead to increased efficiency and investment in the sector. Private companies have the incentive to provide high-quality services to customers to remain competitive and profitable. This can result in improved infrastructure, better water quality, and more reliable service for consumers. According to the regulator´s 2021 annual report, 96 percent of the Chilean customers were served by companies operated by international private groups, with SMAPA the only relevant state-owned company operating in urban areas.

Full treatment of wastewater

Wastewater rates in Chile in the 1990s were on the order of 20 percent. At that time, the government's plan to improve wastewater treatment rates included reforms that allowed the entry of private operators starting in 1998 and helped finance more than US$ 2 billion in investments in wastewater treatment plants that allowed 100 percent of urban wastewater to be treated. Given climate change, proper treatment is only the first step in developing a sustainable approach to transforming wastewater into an economic resource. Although Chile currently treats 100 percent of its wastewater, it does not use it productively. In fact, most of the treated wastewater ends up in the sea. The environmental and economic potential of changing this is enormous: the total volume of unused wastewater could cover almost 10 percent of the country's total hydrological deficit.

Water continuity and improved water quality

The country currently has 100 percent coverage in both drinking water and sanitation. What's more, Chile is one of just two countries in Latin America where the U.S. Centers for Disease Control recommends tap water to be safe to drink. According to a World Bank survey, in spite of the high water stress of the country, just 1.8 percent of the water companies report water supply shortfalls — one of lowest rates among surveyed countries. Additionally, and consistent with the survey mentioned, according to the Chilean Water National Regulator (SISS) the urban areas of the country have a level of continuity of the service of 99.7 percent.

Reduced costs of water and sewage services

One of the most prestigious and up-to-date sources of tariffs worldwide is the Global Water Tariff Survey prepared by Global Water Intelligence (GWI). According to that study, the average global water tariff is 2.34 USD/m^3. The water tariff is composed of fixed and variable charges for drinking water, wastewater, and rainwater collection. Summarizing the GWI data by adding the fixed, variable and tax costs, we conclude that worldwide costs for potable water, sewage collection and treatment, and rainwater collection including taxes are as follows:

- Drinking water: 1.27 USD/m^3
- Wastewater: 0.95 USD/m^3
- Storm water: 0.11 USD/m^3

In turn, the regional composition of tariffs is as follows. In Latin America and the Caribbean, the average tariff is 1.85 USD/m^3. Only the cost of potable water in Latin America and the Caribbean reaches 1.47 USD/m^3. Sewage charges are only 0.38 USD/m^3, probably due to the low level of sewerage (and even less sewage treatment) in most Latin American countries. The cost in Santiago de Chile is 1.23 USD/m^3 (drinking water is 0.59 USD/m^3 and wastewater is 0.65 USD/m^3). The cost in Santiago de Chile represents 1.4 percent of the basket of products of the average household.

The success of the wastewater treatment plan is due to several measures:

1. New emission standards that began to regulate pollutants associated with the discharge of liquid industrial waste into sewage systems and the discharges of liquid waste into marine and inland surface waters
2. Strengthening the supervisory powers of the Superintendencia de Servicios Sanitarios (SISS) in 1998
3. A new regulatory framework that allowed private capital in the sector's companies.

The government's efforts resulted in benefits not only in public health, quality of life, and environmental protection, but also in economic benefits. Specifically, the decrease in wastewater irrigation has increased the potential of the tourism industry and the export potential of agricultural products. From 2000–2017, private companies invested US$ 2.3 billion in wastewater treatment, allowing Chile to reach treatment levels comparable to the most advanced countries in the world.

Aguas Andinas sewage treatment facilities

Aguas Andinas is the largest water and sewage utility in Chile. It provides services to around 40 percent of the Chilean population. Its service areas are in the Santiago Metropolitan Region, where there is 100 percent coverage in drinking or potable water and 100 percent sewage collection and treatment. It is a subsidiary of Veolia Group.

In 1999, only 3 percent of Santiago's sewage was treated; the rest was discharged into rivers together with industrial liquid waste. In turn, the Mapocho and Maipo Rivers were persistent sources of disease and unhealthy conditions in the capital. In 2003, with the inauguration of the La Farfana Treatment Plant, this scenario began to change. Then the Mapocho-Trebal Complex was added, and in just 13 years the city was able to treat 100 percent of its sewage. Thanks to investments of more than US$ 1.2 billion, enteric diseases such as cholera and hepatitis were eradicated, urban spaces were recovered, and riverbanks were repopulated with wild species.

This is the great contribution of the water and sewage industry to the Metropolitan Region. As part of this process, between 2007 and 2010 the company executed the "Mapocho Urbano Limpio" project, a US$ 113 million engineering program that, as of 2011, made it possible to definitively close the 21 sewage discharges that previously fed into the urban channel of this river. It consisted of the construction of a subway interceptor collector of up to 3 m in diameter and 29 km in length, which runs parallel to the riverbed.

The process of decontaminating wastewater to make it fit to be returned to natural watercourses or used for irrigation, in accordance with the standards required by law, is carried out in two biofactories (former sewage treatment plants where residues have been transformed into products): the Trebal-Mapocho Complex (228 million m^3 in 2021) and the La Farfana Plant (247 million m^3 in 2021), and in twelve plants located in different localities around Santiago (34 million m^3 in 2021).

The application of a model based on the circular economy makes it possible to recover the sanitary waste resulting from the purification process carried out in biofactories. Organic waste separated from water during the purification process is used in agriculture and in the regeneration of degraded soils, either directly as biosolids or after processing at the El Rutal Plant, where it is transformed into a dry fertilizer. Some 30,000 hectares benefit from these biofertilizers. This area is likely to multiply in the coming years. The biosolids go through three drying processes at El Rutal: solar, chemical, and resting. The final product has better agronomic properties than wet biosolids due to a higher availability of nutrients thanks to the mineralization generated by the biological process of biosolids. Until December 2021, biosolids from El Rutal were still considered waste and, although they could be used for agricultural purposes, they had to comply with the protocols of the National Waste Declaration System. This will no longer be necessary; in January 2022, the Agriculture and Livestock Service (SAG) certified them as fertilizers. This will speed up their commercialization. In the past year, the first sales of the product were made in this quality and agreements are expected to be signed soon. It is a product with a high nitrogen, potassium, and phosphorus content, as well as a high organic levels, high stability, and very good granulometry, which makes it easier for the plants to absorb the nutrients.

Another by-product of wastewater treatment is biogas, a fuel composed of methane and carbon dioxide, which is generated by the biodegradation reactions of biodegradable organic matter. It is currently used to heat boilers at the plants and to produce energy for self-supply, providing electricity consumed by the Mapocho-Trebal Biofactory. In addition, a sufficient volume is injected into the Metrogas network to supply around 40,000 households in Santiago.

Private Sector's Role in Promoting Water Resilience

In the Santiago Metropolitan Region, the most evident effects of the climate crisis are associated with a drought that has lasted more than a decade and an increase in heavy summer rains in the Andes Mountains. The following section will shed light on the role of Veolia, a private sector company, in terms of facing climate change challenges.

Turbidity events
One effect of climate change is the increase in intense summer rains of short duration in the Andes, which cause displacement of materials that, when falling in the flows, cause high turbidity in the Maipo and Mapocho Rivers, affecting the production of potable water in Aguas Andinas Plants. In order to reduce the main associated risk (the supply cut), the company is investing in major infrastructure works with a goal to increase the autonomy of potable water supply to 48 hours. To this end, the company has invested in new reservoirs, pipelines, and wells. This has resulted in an increase in autonomy from four to 34 hours in a period of seven years. One relevant project was the inauguration of six mega-tanks at Pirque in November 2020, with a capacity of 1.5 billion liters of reserve water. These works made it possible to face the last major turbidity episode, which occurred in January 2021, without supply cuts.

New wells to produce drinking water were also inaugurated. Completed in 18 months, the works consisted of 14 wells with a depth of 300 m, a 20,000 m^3 tank, and a lifting plant. This investment of US$ 33 million will provide an extra 1,500 L/s for the supply of more than 400,000 inhabitants of the southern area of Santiago, as well as increasing from 34 to 37 hours of autonomy in the production of drinking water in the event of extreme turbidity in the Maipo River. The wells operate remotely and are automated to guarantee a safer service and stable pressure.

In turn, the El Manzano-Independent Intake project will further complement water autonomy for the region, operating during instances of extreme turbidity events. It will help secure water without sediment for the production of potable water, tapping into the El Manzano sector 5.7 km upstream of the current Maipo independent intake and providing a flow of 16 m^3/s to the Las Vizcachas production plant. In addition, it will allow filling the Pirque Mega Ponds, adding another 6 m^3/s available for the production of potable water at the La Florida and Padre Hurtado Plants. The project is currently in the environmental assessment, design, and engineering stage.

Droughts
Central Chile has suffered more than two decades of uninterrupted drought. As a result, freshwater sources have suffered a continuous decline. At present, the Metropolitan Region has a worrisome structural water deficit (gap between available water resources and the real needs of the area) of up to 250 cubic hectometers under certain hydrological conditions. This is a limiting situation that will continue over time and could even worsen. Veolia has studied future scenarios, including demand and the behavior of water sources, and its conclusions anticipate a worsening. Given this scenario, Aguas Andinas has defined a range of actions aimed at reducing the water deficit by 2026 through three ways:

1. **Increase efficiency in the use of water resources**: Through its practice of measuring water use throughout the value chain, the company has been able to outline concrete actions to increase water efficiency which reduces the volume of raw water needed to meet the same demand. These actions have concentrated on three priority areas:
    a. **Optimization of raw water intake**: The actions taken by the company to optimize surface water catchment, such as the incorporation of more gates in the rivers, have allowed this activity to be near its maximum level of efficiency. On the other hand, measures are also being

applied to implement state-of-the-art water management of the company's 250 extraction wells. Following a successful pilot plan in 2020 and a corresponding tender in 2021, in January in 2021, a four-year project was initiated with the goal to digitize the wells alongside a more efficient management methodology that will allow us to have more water, less energy consumption, and better control of the associated risks.

b. **Greater efficiency in drinking water production plants**: The advances in operational management issues carried out in 2021 allowed the company to continue advancing in its water efficiency strategy during the following year, achieving new reductions in the levels of losses of the drinking water production plants. The statistics for the year indicate progress. In 2022, 200 L/s of raw water were recovered, reaching a loss margin of 4.8 percent, a figure 0.9 percent lower than in the previous period.

c. **Greater efficiency in detecting and repairing leaks**: Around 30 percent of the drinking water produced by the company ends up as unaccounted for or unbilled water. To address this, the company has a Water Efficiency Plan that is a set of initiatives that seek to speed up the detection of leaks and their repair — tasks that require enormous efforts given the extension of more than 13,000 km of underground network that feeds homes in the capital. In 2021, it was concluded that annually the company was able to detect and repair a number of leaks similar to those produced by the natural deterioration of the network. To break this cycle, in 2022 a project was started to double the detection and repair capacity through new technologies and methods. In the 12 months of its implementation, the recovered water for leaks found and repaired grew from 200 to 500 L/s.

2. **Adding more water resources to the company's matrix**: Since there is a limit to the efficient use of resources, there comes a point when it is necessary to look for other alternatives. Considering this reality, the company is pushing for a series of infrastructure projects and agreements with other users in order to increase the contribution of water to its matrix.

    a. **Groundwater extraction**: Over a three-year horizon, the company aims to increase the amount of potable water produced from underground sources from 15 percent to 30 percent. To this end, it has already implemented several medium-sized projects, adding around 800 L/s to its matrix. Even some sectors in the western and southern areas of Santiago, which had a mixed supply, now have a supply based exclusively on underground resources. In addition to the above, the Cerro Negro-Lo Mena wells add 1,500 L/s to water production.

    b. **Collaboration agreement with irrigators of the first section of the Maipo River**: The yield of Aguas Andinas' rights on the Maipo River (27 percent of the total) is no longer sufficient to supply the city of Santiago. The most feasible solution to alleviate this deficit is to make more surface resources available, which was achieved thanks to an agreement signed in August 2021 with the seven irrigation associations that have rights to use the first section of the river. This agreement is historic for several reasons: for the first time the different users in this sector of the basin recognize the existence of a structural problem that requires a joint and long-term response. Usually, each year the company coordinates with the irrigators to maintain the volume of the El Yeso reservoir, which protects Santiago's water supply, at a safe level, but this new agreement guarantees the permanent availability of the water resource and provides sustainability to the basin through initiatives with an integrated approach. Its most important points include a diagnosis of the management of the first section of the river, which is in charge of a surveillance board, to ensure the maximum level of efficiency. Human consumption is prioritized over other water uses, and if the city's supply requires it, the irrigators will contribute water at a fair price. The agreement entails an obligation to make the necessary water transfers to maintain the safety levels of the El Yeso reservoir and establishes a flow curve that meets the demands of all parties involved. Aguas Andinas commits to implement projects that will make the use of the basin sustainable, including the reuse of treated sewage and the drilling of emergency wells in the irrigators' canal strips to contribute to irrigation. The development of a master plan for the basin by all parties will also consider the future evolution of demands, rainfall, and flows, with a view to ensuring its long-term sustainability.

c. **Reuse of treated water in the bio factories**: The company is studying a series of projects to apply the principles of the circular economy to the region's water supply. The most relevant involves treated water from the Mapocho-Trebal Plant and was included in the agreement with irrigators. The objective is to efficiently and optimally manage the basin, maximizing the availability of water in an equitable manner and allowing a balance in water availability. The project includes a connection from the Mapocho-Trebal Biofactory to the Irrigation Associations of the First Section of the Maipo River, who, in turn, will provide the equivalent of raw water from the river to supply the city, increasing the availability for human consumption. The project is going through the environmental evaluation, design, and engineering stage, and its materialization is scheduled for the next few years. It received a great boost when it was included in the collaboration agreement and obtained the approval of the authorities and different interest groups. It should be noted that, at present, treated flows from the biofactories are already being used for irrigation, but downstream of the biofactories.

Another initiative under study is the infiltration of treated water into the region's underground aquifers to prevent the prolonged drought from depleting their natural recharge capacity. Although it has not yet been scheduled to begin, it is gaining increasing public consensus.

3. **Responsible use campaigns**: A comprehensive solution to water scarcity also requires the involvement of end consumers. For this reason, the company carries out a series of actions to raise awareness in the community about the urgency of using water responsibly.
    a. **Every drop counts**: To reach residential consumers, Aguas Andinas deploys campaigns through its digital networks and constantly reinforces its presence in the media, alerting about the drought and its consequences. On October 25, 2021, it launched the most recent massive campaign for responsible use, which aimed to change the habits of its customers. With the slogan "Every drop counts," companies and other economic sectors such as agriculture and every household in Greater Santiago are invited to join in the care of water.
    b. **Coordinated management with municipalities**: For the last three years between November and April, in view of the large volume of water that municipalities allocate to irrigating green areas, Aguas Andinas delivers to each mayor of the region a report with the detailed consumption of public spaces so that they can check for water leaks. Since 2020 this campaign has shown a positive evolution. That year for the first time the consumption of maintenance of green areas fell, which until then showed an upward trend. This was achieved thanks to concrete measures, such as the replacement of lawns with low water consumption species in squares and the installation of digital meters to monitor irrigation in green areas.

Increasing Resilience for an Uncertain Future

Chile's economic and social resilience relies significantly on fulfilling the water requirements of its water-intensive industries. Unfortunately, the country is facing remarkable water scarcity, which is being exacerbated by an increasing vulnerability to drought. Chile's economic growth has contributed to a surge in water demand in recent decades due to heavy reliance of industries such as mining, agriculture, forestry, and fish farming. However, the challenge of water scarcity is impeding the country's productive activities. For instance, in 2020, water restrictions caused supply-side issues that led to a reduction in copper production, thereby decreasing Chile's exports.

Droughts also threaten social resilience, and in 2021, over 50 percent of the population (19 million people) lived in areas severely affected by water scarcity. According to a study sponsored by the IDB, Chile is currently and will continue to be the country with the highest proportion of its population living in basins with water stress in the coming decades.

Addressing the challenges of climate change requires promoting efficiency in consumption, increasing water efficiency, promoting water reuse, generating new water sources, and preserving the quality of water sources. It is also essential to have a regulatory framework that promotes not only efficiency, but also risk mitigation, encourages investment, facilitates and accelerates the execution and financing of new works, and promotes water savings while maintaining the self-financing of the companies. Investments are needed in reuse of treated wastewater, desalination, infiltration into aquifers, reduction of water losses, lining of canals, reservoirs, wells, and nature-based solutions.

The private sector plays a crucial role in the development of innovative solutions and the implementation of sustainable practices for efficient and effective management of water resources. Within the water sector, they can contribute significantly to the implementation of adaptation policies and programs to address water-related challenges. Private sector operators possess the necessary expertise, access to cutting-edge technologies, and sustainability credentials. As a result, their involvement can facilitate the development of cost-effective solutions and help mitigate the impact of water scarcity with less costs and more efficiency.

Despite the lower availability of water in Chile, the drinking water and sewerage companies have maintained high levels of coverage, continuity of service, and quality standards. Likewise, thanks to the works executed by the private sector, problems due to floods and turbidity events have been avoided. Key attributes to successes were the Chilean regulatory framework and tariff structure that incentivized the private sector to operate in transparency. The private sector companies also assumed responsibility to drive change by not only implementing projects for water reuse and drilling wells for underground water, but also raising awareness amongst residential consumers and deploying water usage awareness campaigns through digital networks.

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Public Private Partnerships to Protect Natural Water Factories: The Case of Colombia's Páramo Wetlands

by Sebastian Sunderhaus[1] and Anna Viktoria Bussmann[1]

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Key Messages

- Colombia's (economic) resilience strongly depends on the water provided by its high Andean wetlands (páramos).
- Public-private partnerships based on the water stewardship approach are a meaningful tool to support the protection and sustainable use of the páramo ecosystems.
- To ensure water and economic resilience, economic actors and private businesses should understand resilience from a macroeconomic as well as a microeconomic perspective and consider the water cycle in a holistic way.

Colombia's Treacherous Water Abundance

The World Bank highlights that although Colombia is one of the nine countries with the greatest water resources worldwide, a third of its urban population is affected by water stress. This issue is increased by the impacts of climate change, which change rainfall patterns and will lead to a rise in average temperatures by up to 2.14 °C by the end of the century. Due to these changes, an increase in extreme events including droughts and floods, a higher frequency and intensity in impacts caused by El Niño and La Niña, and the loss of glaciers is expected (Borja-Vega, de Groot, & Serrano, 2020). Colombia's glaciers have already been drastically impacted by a changing climate. In the last 170 years, Colombia's glacier area has diminished by 90 percent (Ideam, 2023).

Moreover, pollution is increasingly degrading the quality of the country's water resources and damaging its ecosystems. Contributing factors to water stress are mining, unsustainable agricultural practices, and deforestation in watersheds and adjacent areas. Improving water security could avoid up to a 3 percent GDP loss in Colombia (Borja-Vega, de Groot, & Serrano, 2020). The water-rich country faces issues of water security which become visible not only in traditionally dry areas but also during the rainy season, during which time 835 municipal areas suffer from a lack of water. This includes the departments Antioquia, Cauca, Huila, Cundinarmarca, and Norte de Santander (Ideam, 2023).

Colombia's water security depends strongly on its key ecosystems. These include the Orinoquia and Amazon basin as well as the country's wetlands. The term "páramo" describes peatlands that are situated high in the Andes. Half of the world's páramos can be found in Colombia, they are an essential part of the water cycle and 70 percent of the country depends directly on the water they produce (MinAmbiente, 2019). Peatlands are important water reservoirs for flood control and water supply, as their sponge-like properties allow them to release water gradually, reducing the risk of both floods and droughts. This key feature contributes to climate change adaptation. Although peatlands cover only 3 percent of the earth's global land area, they contain about 30 percent of the carbon sequestered on land (about 1,320 t C/ha), which is 75 percent of the total atmospheric carbon and twice the carbon stock in the global forest biomass (Parish et al., 2008).

The Páramo Santurbán: An Essential Wetland for Water Security and Economic Resilience

The high-Andean wetland Páramo Santurbán in north-eastern Colombia provides water for more than two million people in Colombia and Venezuela. This ecosystem covers about 1,300 km^2 and extends across the departments Santander and Norte de Santander. In Norte de Santander, the páramo supplies water to the rivers Zulia and Pamplonita, which connect to Lake Maracaibo in Venezuela. These watersheds are home to one million people. Furthermore, the wetland is essential for the livelihoods of the people living directly in and next to the Santurbán highlands. Most of them engage in traditional farming or mining practices and 95 percent of them depend on the natural resources to guarantee their subsistence.

The Intergovernmental Panel on Climate Change (IPCC) points out that páramos are among the most vulnerable ecosystems. Unsustainable activities are endangering the wetlands' functions as water producers and reservoirs, jeopardizing their role for climate change adaptation and mitigation (Magrin et al., 2014). Short-term agricultural exploitation leads to destruction of the páramos ecosystems as well as high erosion and the contamination of rivers with sediment loads. Increasing temperatures caused by climate change will lead to an upward shift of páramo plants which depend on certain temperatures. Thus, the páramo area will decrease and in the same way the amount of water it can deliver and regulate will diminish.

The water provided by the Paramo Santúrban is undeniably a lifeline for the economy as the region relies strongly on agriculture. This sector is one of the economic categories with the highest water demand as more than 20 percent of Colombia's available water resources are used for agricultural activities (MinAmbiente, 2022). In Norte de Santander, access to water for irrigation ensures consistent crop yields and reduces the risk of drought-related losses. This, in turn, sustains the livelihoods of countless farmers. In the same way, a reliable water supply allows farmers to diversify their crops and increase their agricultural output, explore market opportunities, and export agricultural goods. This not only generates revenue, but also enhances the region's reputation as a reliable supplier of agricultural products.

Beyond farming, water is essential for various post-harvest activities such as food processing, packaging, and transportation. Farmers, laborers, and those involved in related industries depend on agriculture for their livelihoods. A consistent water supply ensures the stability of these jobs and contributes to the region's economic resilience. Moreover, scenic beauty, lush landscapes, and recreational activities linked to water bodies can attract tourists. The tourism industry, often closely tied to agriculture, thrives when natural resources like rivers and lakes are well-preserved, contributing to the local and regional economy.

Public-Private Partnership to Enhance Resilience

MiPáramo is a public-private initiative that includes Bavaria, Alianza BioCuenca (the water fund of northeastern Colombia), the German Technical Cooperation GIZ, the Swiss Agency for Development and Cooperation (SDC), regional enterprises and other local stakeholders, among others. The project is based on cooperation among SDC, GIZ, and Bavaria in the establishment of the waterfund Alianza BioCuenca since 2014. The aim of the current development partnership is to create sustainable economic models for the people living in and around the Páramo Santurbán.

The project follows a water stewardship approach. Its main objective is to enhance water security by building partnerships in which stakeholders take shared responsibility, engage in meaningful actions, and guarantee a socially equitable use of water resources which can be environmentally sustainable and economically beneficial. It is based on three main axes: 1) an analysis of the hydrological benefit of the Páramo Santurbán, 2) sustainable production projects with farming communities, and 3) opportunities for discussion and outreach to engage with all the actors in the region.

At the core of miPáramo lies its engagement with the local communities. Here, a livelihoods approach focusing on sustainable use of the ecosystem becomes pivotal in ensuring water security and thus human well-being. The project offers mining and agricultural communities in the páramo and adjacent areas a sustainable economic alternative in harmony with nature. Farmers can become part of miPáramo through a voluntary agreement and engage in creating a map of their farm in order to determine areas best suited for conservation and production. The conservation areas (usually springs and watersheds) are marked or fenced off to avoid cattle contaminating the water. In the remaining areas, the focus lies on improving sustainable agricultural practices; farmers can participate in capacity building measures to enhance their agricultural productivity without harming nature. They learn how to interpret the state of the soil and how to adapt irrigation techniques and apply organic fertilizers. Additionally, farmers receive guidance on how to improve aspects of their product's value chain — for example, developing an appealing design for the packages of their products. All these activities improve their livelihoods significantly while preserving the watershed. This way, the communities benefit directly from dedicating part of their land to conservation.

The partnership supports 200 farms in becoming increasingly sustainable and protecting 3,500 ha of the wetland area. Furthermore, it informs local stakeholders about the ecosystem's importance for water security, climate change adaptation and mitigation, and biodiversity conservation. The miPáramo Emprende program includes 187 farms (180 family farms), of which 72 (or 40 percent) are run by women. According to a carbon sequestration feasibility study conducted by experts to identify opportunities for Alianza BioCuenca, the carbon stock sequestered in one hectare of coffee (Coffea arabica) is 6.53 tCO_2e/ha (CO2CERO, 2022). Based on this data, the project estimates that the activities in Norte de Santander (60 ha) and Santander (80 ha) could sequester a total of approximately 522 tCO_2. Through the programme, an additional 395 ha of the high Andean Forest and in the wetland of the Páramo Santurbán could be protected, resulting in a total protected area of 673 ha. The preservation of the natural vegetation of the high Andean Forest will make it possible to regulate about 504,750 m^3 of water. This way 16,595 people will benefit from a livelihood of more than 2.5 m^3/person/month, even during extreme drought. Through the protection and sustainable use of the páramo, the important ecosystem services of the landscape are protected and preserved for future generations.

Integrated water resource management and sustainable agriculture practices, particularly near páramos and within watersheds originating in these wetlands, not only enhance livelihoods and well-being of local communities, but can further greatly benefit the wider economy in the region. This includes private companies like Bavaria S.A., a brewery that strongly relies on water resources. The company understands that protecting water sources is essential for its economic sustainability as its beer is made up of 90 percent water.

By engaging in the miPáramo partnership, Bavaria's operations are supported in various ways. The value chain and final product are improved by enhanced water quantity and quality. Sustainable agriculture practices near páramos help maintain adequate water quantity by reducing soil erosion, sedimentation, and contamination. This ensures a consistent and high-quality water supply for the brewery, reducing the risk of water scarcity or the need for costly filtration and purification processes. In the case of the Bavaria plant in Bucaramanga, the company had to pause its production several times for hours in the recent past due to the lack of water or the low quality of water.

Collaboration is essential to maintain the company's operations and can lead to the responsible use and protection of water sources. Engaging with local communities and authorities in water management initiatives helps the brewery secure its water rights and maintain a positive relationship with its neighbors. Investing in sustainable agriculture and páramo conservation enhances the brewery's reputation and fosters goodwill among local communities, potentially reducing the risk of conflicts over water resources.

Supporting sustainable practices in the páramo will lead to cost savings and reduce risks to future operations. Reduced water treatment costs, lower risk of water shortages, and improved water quality all have positive impacts for the company. Furthermore, many regions have regulations related to water use and conservation. Engaging in sustainable practices near páramos ensures that the brewery complies with environmental regulations, avoiding fines and legal issues.

Lessons Learned and the Way Forward

In conclusion, integrating sustainable agriculture and responsible water resource management in páramo regions and watersheds can significantly benefit a brewery's water-dependent operations. It helps secure a reliable, high-quality water supply, benefitting the brewery as well as the communities in the watershed. Furthermore, it enhances environmental and social responsibility and reduces operational costs, ultimately contributing to the brewery's long-term success and sustainability.

The case of the Páramo Santurban shows that due to the exceptionally high diversity of ecosystem functions (water supply/regulation, biodiversity protection, climate change adaptation and mitigation), the páramos can be considered "mega-ecosystems" which must be protected to ensure resilience. To ensure water and economic resilience, economic actors and private businesses must consider the whole water cycle and acknowledge that freshwater ecosystems are key to achieving water security. The high Andean wetlands' essential role in the water supply of rivers and downstream cities must be accounted for, with water resources being at the center of any resilience strategy. Water is not a fixed input and must be acknowledged in all its forms to understand how to make businesses and the economic system more resilient and avoid (future) risks.

The case study reveals how a major company in the region and one of the main water users has understood the importance of water security and enhanced resilience to guarantee its operations long-term and support the financial success of its business. Companies should understand that investing in water and climate and supporting collaborative approaches for enhanced water security is not only a "social practice" but an essential component of maintaining their businesses' performance. By engaging in multi-stakeholder partnerships and supporting water security, businesses minimize their exposure to physical, regulatory, and operational risks and ensure their resilience. It becomes clear that the importance of water resilience for economic resilience must be understood from a macroeconomic as well as microeconomic perspective.

MiPáramo has further inspired different regions and waterfunds. The methodology has been taken up by the waterfund in Bogotá to support water security in the region of the capital city. Moreover, plans are underway for the program to be replicated in Lima, Peru.

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Quenching Grenada's Thirst for Development: Integrated Water Resources Management as Key Aspect of Economic Development

by Magali Bongrand-Henry[1]

[1] Climate-Resilient Water Sector in Grenada (G-CREWS)

Key Messages

- Grenada's economic development is based on two sectors which are heavily reliant on water: tourism and agriculture.
- Grenada's water supply relies on surface water which is at risk due to reduced precipitation, increasing temperatures, and saltwater intrusion in aquifers (climatic reasons) but also due to a lack of reservoir infrastructure to supply its growing population and tourism industry.
- Grenada's aging infrastructure has not seen adequate investments in improvements over the years. This is leading to increasing water losses in the system through leaking pipes. Non-revenue water perpetuates a vicious cycle in which the lack of revenue causes less finance available for investments and therefore more incidents of water losses.

- The Climate Resilient Water Sector in Grenada project (G-CREWS) was developed to avoid critical climate-induced water shortages in the future and to increase systemic climate change resilience in Grenada's water sector.
- An Integrated Water Resources Management (IWRM) approach is key to addressing the numerous challenges facing the water sector, including policy and regulations, infrastructure and tariffs, public awareness, and incentives.

Introduction

Grenada is a small island nation of the Caribbean region with a population of 124,000 inhabitants according to its 2021 census and a GDP of US$ 1.12 billion. The country faces significant challenges in ensuring water security for its economic development. The country's reliance on water-intensive sectors such as tourism and agriculture, combined with the impacts of climate change and aging infrastructure, has highlighted the need for a comprehensive approach to water resources management. The Climate Resilient Water Sector in Grenada (G-CREWS) project aims to address these challenges and enhance water security through integrated water resources management. This case study examines the potential economic benefits of the G-CREWS project in Grenada.

Grenada's Current Economic Context

Grenada's traditional prominence of agriculture in its economy has been replaced in recent years by the tourism industry. Today, tourism plays an important role in Grenada's economy. Since 2018, Grenada has attracted up to 0.5 million tourist arrivals each year pre-COVID, leading to an inbound tourism expenditure of about 46 percent of GDP from just 14 percent in 2013 (UNWTO, 2021). Services, including tourism and education (with the presence of a major American offshore university campus on island), form the largest economic sector with about an 80 percent share of GDP (UNCTAD, 2021). Important infrastructure investments and projects related to tourism have been recently reflected in the growth of the construction sector in Grenada. Today, agriculture represents only 5.8 percent of the country's GDP (UNCTAD, 2021).

Such a sharp growth in water-intensive industries such as tourism, education, and construction are placing considerable strain on Grenada's water resources and infrastructure in that they add temporary users to the country's demographic. For example, tourism plays a major role in water use as the number of annual visitors to the island surpasses the number of inhabitants by many folds.

The agriculture sector is already impacted by the changing climate. According to the IMF's 2022 economic country report, there was a sharp fall in agricultural production, largely due to adverse weather. The Government of Grenada in its 2022 economic report highlighted a fall of 57 percent of the cocoa production, one of Grenada's main export crops, and the Marketing and National Importing Board's (MNIB) purchases of other crops such as fresh fruits, vegetables, and root crops declined by 13.4 percent. This decline is reportedly due to low production caused by limited or low access to water (little to no rain).

Water scarcity, and the resulting decline of agriculture output, has serious implications for Grenada's trade balance as its main export products shrink and the country relies more intensely on importation of food items. At a time when the country could take advantage of an ongoing trend for high quality cocoa, its cocoa production stumbles. The same applies to other highly sought-after crops such as nutmeg and soursop. This is directly impacting the farmers but also the country's trade balance and foreign exchange reserves. It also put in jeopardy Grenada's food security and the ability of its citizens, many of which are in low-income groups, to provide affordable, quality food for their families. Imported food prices have been impacted by increased transport costs and local food prices have also been impacted by the decline in yield.

Yet, the biggest macroeconomic impact of potable water scarcity could be the impact it will have on Grenada's growing tourism industry. A late bloomer in the region, Grenada's tourism industry grew from 40 percent of the country's foreign exchange earnings in 2000 to 88 percent in 2018 and from 21 percent of its GDP in 2000 to 56 percent in 2019 (World Bank, 2019). Yet, Grenada's tourism industry still has a lot of room for growth to reach the earning potential of its more developed neighbors Barbados and St Lucia.

With 25 percent of its population under 15 years old and 75 percent under 55 years old, Grenada's young and dynamic population is ready for economic growth and demanding it from the country's leadership. Hence, the country's economic development is at the heart of the government's priorities. Developers have already recognized that, and the construction industry is booming, with several new hotels being built. Although it is encouraging to see the country developing its potential and bringing opportunities for employment to the young population, this development is also under threat from limited and shrinking critical resources, water being one of them.

Challenges Facing the Water Sector

Grenada relies mostly on surface water sources for its drinking water supply. Many small rivers originate at the center of the island, which is a volcanic mountain ridge peaking at over 800 m and is covered with forest. Annual rainfall is high, from 1000 mm near the coast to over 4000 mm in the central mountains, but there is a very marked dry season from January to May. Water is supplied by the National Water and Sewerage Authority (NAWASA). NAWASA as a public institution in Grenada is by law the only provider of potable piped water. NAWASA operates 28 different water systems, of which 27 are located on the mainland Grenada, with one on the sister island of Carriacou. However, Grenada's aging infrastructure suffered throughout the years from a lack of investments in improvements. This is leading to increasing water losses in the system through leaking pipes; non-revenue water perpetuates a vicious cycle in which the lack of revenue causes less finance available for investments and therefore more incidents of water loss.

Climate change poses a severe threat to Grenada's water supply, since about 90 percent of Grenada's average daily production of 32,700 m^3/day is sourced from surface water intakes. While in the rainy season, the available water resources exceed the water demand, there is a considerable deficit in the dry season as the river catchments are too small to store enough water during the rainy season. Along with the increase in average temperature due to climate change, this deficit causes a serious current and potential threat as annual rainfall is projected to decrease by up to 21 percent, leading increasingly to droughts. Saltwater intrusion in coastal groundwater aquifers due to sea-level rise will further limit the availability of water in the future. In addition, more frequent heavy rainfall events — predicted as another major impact of climate change — aggravate the problem of more frequent water supply outages due to high turbidity in the raw water supply.

Finally, more frequent catastrophic events such as hurricanes are predicted as climate change intensifies. Although the Caribbean chain of islands has been in the path of seasonal hurricanes and tropical storms historically, the small countries still need to build more resilience to these catastrophic events. This is due to a number of reasons, the main one being scarce access to finance to improve infrastructure in ways that would help it withstand devastating storms. When Category 4 Hurricane Ivan hit Grenada in 2004, not only was 80 percent of its housing stock either destroyed or seriously damaged, but the country's electricity was cut out for up to 6 months in some areas and up to 30 days for the water supply.

The damages from Hurricane Ivan in Grenada were estimated at US$ 900 million, or twice the GDP. The lack of critical utilities such as water and electricity meant that it took longer for Grenada and its citizens to get back on their feet. The damages to the water infrastructure alone was estimated at US$ 2.82 million — very significant in terms of the state-operated NAWASA, which had little or no insurance protection from natural disasters and has a small average revenue base.

Reducing Water-Related Economic Vulnerabilities with the G-CREWS Project

The Climate Resilient Water Sector in Grenada (G-CREWS) project was developed to avoid critical climate-induced water shortages in the future. As such, the main objective of the G-CREWS project is to increase systemic climate change resilience in Grenada's water sector. The project supports Grenada's water sector in using water resources more efficiently and in improving water availability using an integrated approach to water management. To reach its broad objectives, G-CREWS is jointly financed by the Green Climate Fund (GCF) and the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) under its International Climate Initiative (IKI), and the Government of Grenada. Over six years, the Government of Grenada, the Grenada Development Bank (GDB), and NAWASA, in partnership with the German Development Cooperation (GIZ), implemented the project with a total budget of €45.297 million. The project supports the water sector's comprehensive transformation on multiple levels, which represents a nationwide paradigm shift for Grenada's overall resilience. The project is articulated around five main components:

1. **Climate-Resilient Water Governance**. Previously, Grenada managed its water resources mainly through the national water utility, NAWASA. However, this simple approach, where the national water utility acted as the regulator, didn't allow for a comprehensive and transparent management of resources. This approach didn't consider national policies, involve various stakeholders, or centralize statistical data from these stakeholders.

   With the development and adoption of a Water Resources Management and Regulation Act paving the way to the set-up of a

Water Resource Management Unit (WRMU), Grenada will strengthen the overall water governance of the tri-island state and will set out the conditions for sustainable water resource management which follows the Integrated Water Resources Management (IWRM) approach.

This newly established WRMU, overseen by the Public Utilities Regulatory Commission (PURC), now holds the responsibility of managing Grenada's water resources holistically. This will be achieved by collaborating with stakeholders, businesses, and civil society, and by conducting awareness campaigns and public outreach. The overarching vision is of "[a] water secure Grenada in which stakeholders are treated equitably and fair." The WRMU is tasked with regulating water resources, ensuring their protection, facilitating information sharing, and responding to climate change. This approach will empower Grenada to have better oversight over water usage for both social and economic development. Other regulatory changes include the integration of rainwater harvesting into the building codes and the phasing out of water-inefficient sanitary ware.

2. **Climate-Resilient Water Users**. The Grenada Development Bank is implementing the Challenge Fund to assist farmers and hoteliers to integrate water saving measures into their daily businesses. Under the fund, selected farmers and hotels will receive grant finance to install water saving devices such as low-flow toilets and drip irrigation systems. In addition to reducing the general water consumption, these measures will also reduce operational costs for businesses. The project also integrates a large public awareness component to trigger a behavior shift in the general public about their use of water and water conservation measures. Through a coordinated communication and sensitization strategy involving community and school outreach, brochures, advertisements on multiple media channels, interviews and other outreach activities, the G-CREWS project is already seeing this shift happening.

   A 2023 mid-term Knowledge Attitudes and Practices (KAP) Survey revealed an uptake of water saving measures among Grenadians in their daily lives: taking short showers, turning off the water while brushing teeth, doing full loads of laundry, checking for leaks, as well as using rainwater to wash vehicles and cleaning the yard, to cite a few. The survey showed a positive progression of understanding the link between water usage and water bills as well as the added value of water saving devices. Citizens' understanding of the link between climate change and the water supply system was confirmed by 75 percent of the responders.

3. **Climate-Resilient Water Supply Systems**. The bulk of the project's finance is being used for infrastructure improvements and the supply of additional storage tanks to ensure that Grenada's water supply is stabilized even throughout increasing droughts or disaster. In addition to infrastructure investment, the project seeks to use better technology for system mapping, data collection, and reporting so that leaks can be detected, reported, located, and repaired faster.

4. **Additional Contributions of the Water Sector to Grenada's Climate Goals**. Under the G-CREWS project, NAWASA, aims to move towards a CO_2 neutral water utility by 2030 by reducing its electricity-based CO_2 emissions. This goal is to be fulfilled by implementing energy saving measures as well as integrating renewable energy throughout its operations. This will also support the financial viability of the water service structure by bringing the running costs down.

   In terms of energy management opportunities, the two main areas of savings consisted of replacing the utility's outdoor lights with solar LED lights and replacing the energy inefficient and high greenhouse gas potential AC units with modern inverter units. Together these measures were expected to save 2 percent of the utility's annual energy bill. Yet, the biggest impact on its CO_2 emissions will be achieved through producing renewable energy from and for its own water production. The utility plans to utilize its land and roof space to install PV (solar) panels which in turn will power the water pumps used to send water uphill to reservoirs and storage tanks. The utility is also exploring the potential to install micro power turbines which act both as hydropower generating units and pressure reducing valves on its gravity-fed pipes network.

5. **Regional Learning and Replication**. The project supports Grenada in becoming a regional frontrunner for climate-resilient water management. The creation of a regional community of practice, which brings together key players from the water resources sector in the Caribbean, as well as the implementation of a knowledge management platform to share lessons learnt and other important outputs from the project, will support other countries in region in developing and implementing their own sustainable water resources management efforts.

Conclusions

The G-CREWS project in Grenada represents a comprehensive and integrated approach to address water vulnerabilities and enhance water security. By focusing on climate-resilient water governance, infrastructure improvement, behavior change, renewable energy integration, and regional collaboration, the project offers significant economic benefits and lays the foundation for sustainable economic development in Grenada. It serves as a model for other countries facing similar challenges in the Caribbean region and beyond, highlighting the importance of integrated water resources management for long-term economic resilience.

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Australia: Economic Resilience Through Adaptation in the Murray-Darling Basin

by Sarah Leck[1], Huw Pohler[1], Sarah Ransom[2], and Katharine Cross[2]

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Key Messages

- The prolonged Millenium Drought served as a major catalyst for reform for Australia's Murray-Darling Basin.
- Neglecting the environmental health of the Murray-Darling Basin has in the past led to adverse economic consequences. Balancing the needs of both the environment and the economy is essential for long-term sustainability and resilience in the Murray-Darling Basin.
- The use of new market-based instruments has proven to be a viable and efficient way to allocate water resources even amid changing conditions.
- Despite the improvements in policy instruments and objectives, challenges remain in ensuring that water management reflects its economic, environmental, and cultural values.

Introduction

Australia's Murray-Darling Basin (MDB) is the continent's largest river system, crossing four states and one territory.

The Murray-Darling is foundational to the economic, cultural, environmental, and community health of much of southeastern Australia, and is managed under difficult climatic conditions, including periods of severe water scarcity.

For more than 65,000 years, First Nations people have sustainably managed the lands, waters, and natural resources for the health of their country and people. First Nations people in Australia have understood the importance of water and its centrality to life and have cherished it accordingly. Traditional ecological knowledge, often in the form of stories, is passed down from generation to generation, continuing to this day. This allows a symbiotic relationship with the land and water.

This case study focuses on changing water management since the mid-twentieth century. It explains how evolving perspectives on the value of water have driven adaptive management of the system through past climatic extremes. The story of the governance of the MDB for greater resilience has not been linear or uncontested, and the framework continues to evolve with new pressures from climate change. In the future, effective water management will be even more important to ensure social, environmental, and economic resilience during periods of reduced water availability.

Droughts as Leverage for Water Reform

Significant development of the MDB's water resources began during the early twentieth century, with a focus on dams, agriculture, and service provision. By the 1960s, the water economy had begun to mature, and relatively low-cost sites for constructing dams and other infrastructure were largely exhausted.

The costs of water capture and use, including infrastructure and service provision costs, became increasingly visible, as did the environmental costs. Salinity was affecting agricultural land, thereby negating some of the benefits of the water system for agricultural production.

By the 1980s, water supply options were decreasing even further, while demand for water was continuing to increase. The 1982–1983 drought across eastern Australia, one of the worst of the twentieth century (BoM, n.d), underscored the need for a change in water management. The focus of Australia's water resources management began to shift to managing limited water resources more efficiently and sustainably to increase resilience. There was growing awareness of the need to address increasing water scarcity and environmental degradation, including the implementation of volume-based licenses to limit water use.

Through the 1980s and 1990s, water management objectives began to account for both the wider costs and benefits of water use. This meant maximizing the economically efficient use of water while limiting environmental costs and impacts. Instruments to achieve this included:

- government commitments to capping total water consumption and allocating water for the environment
- enabling water trading
- applying full cost recovery and consumption-based pricing principles.

The increasing complexity of policy instruments was justified by increasing demands and scarcity, and the need to address legacy approaches that did not reflect the multiple competing values of water use. There was a growing understanding of the connection between water scarcity, environmental degradation, and agricultural and economic outcomes for the region.

A further extreme drought between 1997 and 2009 (referred to as the Millenium Drought) put existing infrastructure, policy, and economic structures to the test in the management of scarce water resources.

The Millennium Drought

During the Millennium Drought, southeastern Australia experienced unprecedented dry conditions. By the summer of 2006–07, the Murray River experienced its 10th consecutive month of record low inflow. In the 10-month period from June 2006 to March 2007, the inflow was 770 gigaliters (GL), which was less than 60 percent of the previous minimum of 1,350 GL in 1982–83 (MDBC, 2007). Melbourne's water storages plummeted from 97.5 percent full in October 1996 to only 33 percent by June 2010. In 2006, the inflows into the Murray system hit an all-time low, and only irrigation releases kept the river flowing, unlike in previous droughts in the first half of the twentieth century (BoM, n.d).

Despite efforts to adapt to these conditions, water carting (i.e., bringing water supplies by trucks) was required to maintain essential water supplies for several towns and rural supply systems, major infrastructure projects were brought forward, irrigation allocations were the lowest on record, and water shortages were declared. The worst impacts of the drought were borne by the environment rather than consumptive users. This was because environmental flows were sourced from unregulated flows or spills from storage, which ceased during the drought. Secure entitlements still received a share of the limited water available, increasing resilience to low water availability for these users (DELWP, 2016).

There was a significant decline in the production of yearly crops in the basin from 2002 to 2009. The production of irrigated rice and cotton fell by 99 percent and 84 percent respectively. Conversely the production of perennial crops was only 32 percent lower from 2003 to 2007. Additionally, between 2007 and 2008, the Gross Regional Product in the southern MDB experienced a 5.7 percent decrease from the projected amount, leading to the temporary loss of 6,000 jobs. In the Murray region, tourism revenue in 2008 decreased by an estimated AUD 70 million due to fewer visitors (AWP, 2016).

As well as severe reductions in environmental flows, many urban centers in the basin suffered severe water restrictions as the drought affected runoff into water storages used to supply urban populations. The cost-reflective pricing used to set urban water tariffs meant that there was limited ability to increase prices as a mechanism to reduce demand. Governments therefore had to enact comprehensive restrictions on water use to protect limited supplies. In 2005, around 80 percent of city dwellers in Australia were subject to long-term water-use restrictions (Productivity Commission, 2008). These restrictions were applied very broadly and prices were mostly not used to change demand. Urban water prices therefore could not accurately reflect urban water users' willingness to pay for water consumption and so were less effective in maintaining economic resilience for urban areas.

The Millennium Drought was particularly significant due to its interaction with the effects of climate change. The temperatures experienced during this drought were higher than those seen in previous droughts. These higher temperatures affected the intensity of the drought, leading to increased evaporation and affecting the health of animals and vegetation. The drought may also have been affected by climate change-induced alterations in rainfall patterns. Over the past few decades, there has been a significant decrease in rainfall during April to October in both southwest and southeast Australia. This trend towards drier seasons may have contributed to the Millennium Drought by preventing recovery between periods of acute dryness (BoM, n.d).

Reforms in Water Resource Management Because of the Millenium Drought

The prolonged Millennium Drought prompted a series of major changes in water management. There was an escalation in reforms to try to achieve previous commitments which had not been achieved, as well as addressing historic overallocation of water. The Australian Government also proposed an increased federal role in the management of water resources in the MDB due to challenges in the effective management of resources across state boundaries.

Initial reforms to address environmental and cultural issues and improve the functioning of water markets

In 2003, the MDB Ministerial Council announced the “First Step Decision” to recover 500 GL of water for the environment for six sites of high environmental importance along the Murray River and to construct infrastructure to increase the efficiency of delivery of water for the environment (DEW, n.d.).

In 2004, the National Water Initiative (NWI) was implemented. It proposed clear and nationally consistent characteristics for secure water access entitlements to improve their security and commercial certainty by specifying their statutory nature (NWC, 2011). The NWI also sought to improve the effectiveness of water markets, including by further unbundling land and water rights, and removing artificial barriers to trade such as administrative restrictions. Under the initiative, jurisdictions agreed that water access entitlements and planning frameworks would recognize the needs of First Nations Australians in relation to water access and management for the first time. Commitments were made to include Indigenous representatives in water planning, wherever possible, and incorporate Indigenous social, spiritual, and customary objectives — and strategies for achieving them — in water plans. Provisions were also made to consider the possible existence of native title rights to water in water planning processes, and to account for water allocated to native title holders for traditional cultural purposes (Productivity Commission, 2017). This represented a significant change in the management of water and provided an opportunity for increased social and economic resilience for Aboriginal and Torres Strait Islander peoples by appropriately reflecting their values in the management of water resources.

Major changes in the management of water in the MDB

In early 2007, the Australian Government released the National Plan for Water Security. The plan continued the direction of reform set out in the National Water Initiative. It also included more than AUD 10 billion of new Australian Government funding to address overallocation in rural Australia through investment in irrigation infrastructure and buying back permanent entitlements for the environment (Australian Government, 2007). After a change of government later in 2007, the plan evolved into the Water for the Future program, with a budget of more than AUD 13 billion. The Water for the Future program included some initiatives to increase urban water security; however, it also had a significant focus on the MDB. It supported farmers and communities to increase resilience by planning for a future with reduced water availability and encouraging sustainability, irrigation productivity, and improved river and wetland health. Water for the Future has three main elements (NWC, 2011):

1. the Murray-Darling Basin Plan (the Basin Plan), implemented by the Murray-Darling Basin Authority (MDBA) to provide for the integrated management of water resources and to set scientifically-based sustainable diversion limits
2. buybacks of water entitlements for the environment from irrigators and their assignment to the Commonwealth Environmental Water Holder (or state equivalents)
3. extensive investment in more productive irrigation systems.

These major changes to water management in the basin were given effect in interstate agreements and the Commonwealth Water Act 2007. The Act provided the legislative basis for the Murray-Darling Basin Plan, which is now effectively a transboundary water planning and legislative instrument to manage water resources in the basin.

The Basin Plan – a new approach to managing water resilience

The Basin Plan was established by the Australian Parliament in 2012 to recover 2,750 GL of water for the environment from an annual consumptive use of 13,623 GL, or to implement projects that deliver "equivalent" environmental outcomes. The Basin Plan did not set the level of recovery to account for the impacts of climate change, particularly in the southern basin. At the time there were questions raised about how the final level of water recovery was identified and whether there was sufficient scientific evidence to support the agreed level. This lack of transparency led to some ongoing issues of trust and confidence in the Basin Plan, affecting its delivery.

Following amendments to the Basin Plan under the Sustainable Diversion Limit Adjustment Mechanism, the overall target for water recovery was set at 2,075 GL per year (GL/y) plus 450 GL/y to support enhanced environmental outcomes. The Water for the Environment Special Account (WESA) was established in 2013, with AUD 1.775 billion to fund efficiency and constraint measures that would contribute to enhanced environmental outcomes. The Second Review of the WESA, released in August 2022, found that only 2.6 GL/y of the required 450 GL/y has been recovered, and that full recovery through efficiency measures would likely cost between AUD 3.4 billion and AUD 10.8 billion (Australian Government, 2021).

Overall, since 2012 there has been mixed progress in implementing the water recovery targets set under the Basin Plan. A series of institutional changes since 2012 have eroded regulatory oversight and confidence in national water reform. In 2013, the MDB Ministerial Council abolished the Sustainable Rivers Audit, a program established to measure the condition of the river systems in the basin. In 2014, the Australian Government abolished the National Water Commission, and, in 2017, revelations of possible water theft and meter tampering exposed inadequate monitoring and compliance regimes (Wentworth Group, 2017). The general functioning of the MDBA has also been called into serious question, particularly the transparency with which scientific research has underpinned some decisions (Walker, 2019). Water recovery targets originally set under the Basin Plan were to be delivered by 30 June 2024; with any deficiencies assessed per the reconciliation process provided in the Water Act. These targets are not expected to be achieved and the timelines have been extended by three years (DCCEEW, 2023a).

Other recent changes have included the reinstatement of the NWI. A review by the Productivity Commission found that the NWI should be renewed and modernized to better account for changes in knowledge and technology and to address emerging challenges such as climate change and population growth (DCCEEW, n.d.).

River Basin Management As a Climate Adaptation Tool

The system in the southern MDB now provides an advanced approach to water allocation, enabling a flexible and resilient approach which can better respond to climate risk and water scarcity. The approach relies on a number of fundamental requirements to function effectively, including:

- robust planning frameworks
- stakeholder consultation
- clearly defined property rights
- metering and monitoring
- strong regulatory arrangements (including compliance)
- a reliance on economic principles.

The allocation system performs well, particularly given the highly variable supply of water in southern Australia and the prevalence of periodic droughts. As a result of the current system, a highly effective water market has been achieved in the MDB.

The allocation system supports a high-performing, modern, and globally significant agricultural sector, valued at around AUD 24 billion annually. Australia is one of the most food-secure countries in the world (in the top 10), producing much more food than it consumes and exporting around 70 percent of agricultural production. Production has moved, and continues to move, towards higher-value and more efficient agriculture (including various forms of horticulture) and away from low-value crops and industries. However, there is still a large diversity of farming, including irrigated production of cotton, vegetables, rice (with a significant export industry), dairy, and almonds. Importantly, water moves between crops over time, facilitated by markets, which means that a different crop mix can be grown when water is scarce versus when it is more abundant.

The water market is one of the key factors underpinning the ongoing success of irrigated agriculture in the southern MDB, including significantly reducing the economic impacts of drought and helping to manage the risks of climate change. Water markets are now integral to Australia's regional economies and help to support production and growth in these regions. This approach can enable agricultural producers and other industries to flexibly meet their water requirements, and balance risks and returns. They have greater resilience in the face of a changing climate due to the ability to better adapt to changing water availability. This was seen during the Millenium Drought where water trading was highly effective in reducing the economic costs (for the agriculture sector, specifically), with the gross value of irrigated agricultural production in the MDB falling by only around 14 percent between 2005–06 and 2007–08, while water use fell by 57 percent (Goesch et al., 2019).

The functioning of water markets has also been tested more recently during a period of drought between 2017–2019. Many areas of the country experienced high temperatures and rainfall that is well below average; 2019 was the warmest and driest year on record for Australia (BoM, n.d.). These severe drought conditions adversely affected economic activity. Farm GDP declined by around 30 percent between 2017–2019 — comparable to the decline observed during the 2002–03 and 2005–06 episodes of the Millennium Drought (RBA, 2020).

In 2019–20 the area of summer crops planted in New South Wales was 79 percent less than in 2018–19. The area planted for cotton fell by 83 percent due to low irrigation water supply and soil moisture levels that were insufficient for dryland cotton crops (ABARES, 2020). However, once the drought broke in 2020–21, there was a significant increase in plantings as markets recovered. In 2021–22 the area planted for cotton in NSW increased by 111 percent (193,000 to 406,000 ha) compared to the previous year. It was the largest area planted for cotton over the last 30 years (when ABARES records began). The area planted for rice in NSW increased 35 percent (45,100 to 61,000 ha) (ABARES, 2022).

Without direct exposure to water markets, there is no corresponding mechanism to account for value in environmental and urban water use. Before the Millenium Drought, the expectation for water utilities was that they would provide clean, reliable, and affordable water and wastewater services. However, the Millennium Drought highlighted the importance of water and water environments to both urban and rural communities, both for water supply and for amenity, recreational, and environmental outcomes. Local lakes and streams dried up (particularly in regional communities), and urban communities had limited water use due to restrictions. As a result, there has been a greater appreciation of the contribution that water management and water environments can make to amenity, livability, recreation, and regional tourism (Productivity Commission, 2017). The tourism industry in the MDB is now estimated at AUD 11 billion per year (MDBA, n.d), increasing the importance placed on managing environmental assets to ensure ongoing tourist visitation to the area.

Since the Millenium Drought, the environment has been established as a legitimate water user. Water plans now include an identified sustainable volume available for consumptive use, helping to limit further environmental degradation. There has also been a reallocation of water from consumptive use to the environment in overallocated systems (Productivity Commission, 2017). Governments have changed throughout the process and not all targets are on track to being achieved, but the commitment to returning water and achieving the long-term annual average targets has been bipartisan (although there has been contestation of the approach from different jurisdictions). Repairing the long-term environmental degradation in the basin will be an ongoing process, but there are some early indications of the benefits of increased water for the environment. Environmental water provisions have contributed to improved local ecological outcomes such as breeding of native fish, frogs, and waterbirds, improved conditions of native vegetation, and better water quality (MDBA, 2020).

Most jurisdictions have improved their engagement with Indigenous communities for water planning and management (NWC, 2014). The Basin Plan required water resource plans for the states and territories to identify Indigenous outcomes. Ensuring that cultural values are recognized and provided for in water plans has been an ongoing aspiration for Indigenous communities, leading to the inclusion of provisions in the NWI to meet that goal. In recent years, some states and territories have made progress in ensuring that water planning includes adequate consultation with Indigenous communities, but this is yet to translate into explicit detailing of cultural values and outcomes in water plans (Productivity Commission, 2021).

Effective Policy Instruments for Increased Water Resilience

The two key policy instruments that have been most effective in improving water resilience and economic resilience in the MDB are cap-and-trade mechanisms and cost-reflective charges for infrastructure and services:

- Cap-and-trade mechanisms have been used to create a market for surface water that has enabled water to be reallocated to more productive uses and return water to the environment in overallocated systems.
- Cost-reflective pricing has been used to identify appropriate levels of investment in infrastructure and service provision. It has enabled high levels of service with very low water losses in Australia in comparison with other countries.

These instruments are discussed in more detail below.

Cap-and-trade mechanisms

Water markets were primarily introduced to allow users to manage water within a total limit, and drive more efficient and higher-value water use by signaling the scarcity of water. In broad terms, the objective of water markets is to efficiently manage the allocation and reallocation of water among competing users, given scarcity. Effectively managing reallocation of water enables increased resilience in the face of climate change, drought, and decreasing water availability.

Water markets were seen as the most effective way of allowing reallocation between users, as they allowed water users to make decisions about the value of water based on their intended uses. In the absence of a market, there would be no opportunity for reallocation, or the government would need to unilaterally assess and reallocate water (which it is not well placed to do). The introduction of water markets was concerned with achieving both economic efficiency and environmental sustainability.

The water market placed decision-making in the hands of individual private enterprises and users and, by design, required gains from trade for buyers and sellers for any reallocation (trade) to occur. With the presence of appropriate rules to manage third-party impacts, trade provides a more fair and equitable approach, as well as being more efficient (NWC, 2011). Australia's water markets, and the supporting institutional, regulatory, and operational settings, are now well developed. These outcomes are the product of a long period of hard-earned reforms.

Australia now has many systems that enable market-based trade including:

- entitlements with clear characteristics
- comprehensive registers
- fast trade processing times
- interstate trade
- deep broker markets.

There are now large volumes of water trade and a wide range of participants. Barriers to trade have been removed, and the remaining rules are generally for hydrological reasons only, to protect third parties and the environment, and are clear and well understood. While there has generally been increasing interregional trade, trade restrictions can still occur which can affect prices during periods of low water supply.

Cost-reflective pricing

Water tariffs in Australia are currently designed with the objective of economic efficiency through the use of cost-reflective pricing. Independent economic regulation has been key to cost-reflective pricing. The NWI required that independent economic regulators have a role in the review or setting of prices for water services. Independent economic regulation encourages efficient service delivery by applying rigorous scrutiny to operational and investment decisions. It facilitates consistent and improved planning, increases the transparency of decision-making, and reduces the risk of political interference in price-setting processes. Cost-reflective pricing is now used for urban water supply and wastewater management, and for major irrigation schemes.

Water efficiency initiatives during the Millennium Drought were extremely effective in decreasing per capita water use. This reduction in water use has been maintained even after the drought ended. Utilities across the country can continue to provide high quality safe and secure supplies — even when faced with extreme climatic events. It is estimated that households and businesses are now saving over AUD 1 billion a year on utility bills as a result of the Water Efficient Labeling and Standards (WSAA, 2019).

In the urban sector, the move to cost-reflective pricing was often accompanied by the introduction of some level of consumption-based pricing. Along with restrictions and awareness campaigns during droughts and regulatory changes, this resulted in changed consumer behavior and lower household water use (Productivity Commission, 2017).

Most major irrigation areas also now achieve full cost recovery of both capital and operations and maintenance costs. In broad terms, irrigators in Australia have very high levels of service compared with other countries, including on-demand ordering, high levels of automation, relatively low levels of water losses, sophisticated billing, customer, and information services, and metering and monitoring. However, a constant challenge is the tendency to “gold plate,” or overinvest, in assets without sufficiently considering the ongoing maintenance costs that irrigators must continue to meet. Despite privatization, investment in rural water infrastructure often becomes a political issue, with evidence on the economic and environmental costs and benefits being ignored if it does not meet the political desire for investment.

Major Challenges in the MDB

Although there have been many successful reforms over the past 100 years, and positive environmental, economic, and social outcomes have been achieved, the MDB still faces challenges. Water recovery in some districts has often compounded or occurred in parallel to the many other economic pressures facing rural and regional Australia, which have led to significant challenges for many agricultural communities. For example, while individual irrigators have benefited from various reforms, less than 1 percent of the AUD 13 billion allocated to water recovery through the Water for the Future program was made available to assist communities affected by the reforms to adapt to a future with less water. A consistent approach to identifying the costs and benefits of water reform, which focused on economic resilience for affected communities, would also enable more effective delivery of environmental outcomes by increasing buy-in and goodwill for reforms. Governments face challenges in addressing these issues without negating the benefits that water markets generate.

Challenges have also arisen in the effective functioning of water markets. A recent review by the Australian Competition and Consumer Commission (ACCC, 2021) concluded that the governance, regulatory, and operational frameworks supporting water markets have not developed to accommodate the current scale of the market and are no longer adequate. A serious consequence of these problems is that many water users do not trust that the markets and key institutions are fair or working to the benefit of water users, particularly irrigation farmers. This hinders further reform and can also lead to issues such as reduced compliance or water theft.

The implementation of the Basin Plan since 2012 has achieved important results, with progress and measurable outcomes observed at the basin scale. However, the Basin Plan cannot effectively support many floodplain and wetland ecosystems until critical water infrastructure is improved and river operating rules are in place. Several major fish death events in 2019 demonstrate the need for whole-of-system management and the urgency to address some of these matters. The Basin Plan, and the state and territory governments implementing it, must continue to adapt and improve approaches to managing water quality and salinity, particularly in the context of low- or no-flow conditions (MDBA, 2020).

Despite progress, there is also a growing divide between perceptions and reality with regard to water management. Some communities feel that social and economic conditions are declining as a result of water reform, and that the government has failed them. This is often connected to broader economic trends. Larger communities have generally thrived, whereas smaller communities have suffered as a result of structural adjustments such as population decline and changing industrial structures. In particular, there has been resistance to buybacks for environmental water, even though it was the least-cost approach from a society-wide perspective. The government response had previously been to invest in on- and off-farm water infrastructure to deliver water savings, which have been converted to water licenses held by environmental water holders (purchased licenses are also given to the same public environmental water holders). More recently, there has been a renewed commitment to buybacks to meet the shortfalls in recovery targets under the Basin Plan (DCCEEW, 2023b)

Summary

Water policy in the basin is now designed to support an open and flexible economy, resilient and adaptive businesses, cultural values, and a healthy environment. The current objectives of water management reflect an increasing acceptance of the need to value water across its many competing uses, to support improved resilience in water use, and in economic, social, and cultural outcomes for the community. The policy instruments in the basin have been developed to support these aims and objectives.

Successive governments have contributed to increased efficiency, growth, and productivity through competition reforms and deregulation across all sectors of the economy. This is seen in Australia's highly unsubsidized and unregulated agricultural sector, and in water entitlement and market reforms. Although there have been setbacks, this strategy has achieved positive results and could provide a model for other countries or regions wishing to develop a strong and resilient water sector.

Despite the improvements in policy instruments and objectives, challenges remain in ensuring that water management reflects its economic, environmental, and cultural values. There is scope to further refine the approach to water policy and management in the MDB. This includes: 1) addressing stakeholder misperceptions and angst, 2) better achieving and demonstrating outcomes for communities, industries, and the environment, and 3) applying more flexible and effective reforms that focus on improving water resilience, particularly in the face of climate change. Recent experiences of extreme dry conditions in the basin and community discontent highlight the importance of these different uses and values and their tradeoffs, and the continued need for policies to focus on increasing resilience. Failing to do so leaves water policy vulnerable to short-term decision-making and uncertain long-term costs.

Improving the ways in which we manage competing water use and values in the basin can help ensure that the right policies and levers are used to benefit the community as a whole. The increasing value of scarce and variable water supplies in the face of climate change underscores the importance of getting policy and management implementation right, including managing tradeoffs across communities, industries, and the environment.

Lessons Learned

Water management in the Murray-Darling Basin has yielded several key lessons that have informed and reshaped policies and practices:

- **Drought and periods of low supply can be used to deliver positive water reform**. The prolonged Millenium Drought served as a major catalyst for reform. It demonstrated the MDB's vulnerability to extended water scarcity, prompting policy-makers to address longstanding issues in water management. Increasing the resilience of the region to periods of reduced water supply, including economic, social, and environmental resilience became a major focus for policy-makers.
- **Market-based instruments can be highly effective in promoting economic resilience**. Water trading and the establishment of water markets have emerged as powerful tools in the Murray-Darling Basin. These mechanisms enable a more efficient allocation of water resources, empowering farmers and businesses to adapt to changing conditions and make informed decisions regarding water usage, thus bolstering their economic viability.
- **Failure to account for the impacts of climate change can undermine**

effective water management. Climate change poses a growing threat to water availability in the MDB, and overlooking these effects can lead to mismanagement of water resources. It is imperative that water management strategies integrate climate data and scenarios to prepare for the long-term challenges posed by a changing climate. Investment in adaptation measures, such as robust water storage and distribution infrastructure, must also account for the expected effects of climate change.

- **Collaboration with local communities and stakeholders is vital in the effective management of water resources**. Engaging with and involving Indigenous groups and communities in decision-making processes not only fosters trust but also ensures transparency in water management. It allows for the consideration of the diverse needs and perspectives of the MDB's residents, making policies and actions more responsive to the real-world challenges faced by the community.
- **There is a clear link between environmental and economic outcomes and resilience**. Neglecting the environmental health of the Murray-Darling Basin has in the past led to adverse economic consequences. Ecosystems within the basin provide vital services such as water purification, salinity management, and biodiversity which supports both the agriculture and tourism industries. Recognizing the interdependence of these outcomes is critical for sustainable water management. Balancing the needs of both the environment and the economy is essential for long-term sustainability and resilience in the Murray-Darling Basin.

The experiences and lessons learned from water management in the Murray-Darling Basin since the Millennium Drought have reshaped policies and practices. These lessons are crucial as the region continues to navigate the complex challenges of water resource management.

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PART 3

Enabling Economic Resilience: Seven Modalities for Implementation

Mode 1: Intra- and cross-sectoral planning can define economy-wide resilience priorities for growth

While both public and private sectors have critical roles to play around economic resilience, articulating a vision of the goals and strategies for economic resilience almost certainly must come from the public sector, major public finance, investment, and regulatory bodies. For many countries, transboundary resource sharing is a critical consideration as well.

1. Define resilience as a measurable concept. Implement transparent and specific, measurable, achievable, relevant, and time bound (SMART) measures to inform all stakeholders about how the system is evolving.
2. Assess and evaluate the intrinsic relationship between economic growth and water consumption. Measure the total economic value of water, its contribution to different sectors in the economy, and the sensitivity of the economy to disruptions in water.
3. Modify national macroeconomic models, general equilibrium models, and balance of trade forecasts to include factors such as water uncertainty, dynamic hydrology, and risk assessments. This adaptation should involve creating an interface that integrates microeconomic models of water use, ensuring a comprehensive understanding of how water-related issues impact broader economic systems.
4. Set variable targets for water use according to expected limitations and needs for river basin closure in specific territories. Promote activities with flexible operating rules to adjust water use and quality according to resource variability, economic value, types of activities, sustainability, or level of competition.
5. Water scarcity / drought programs should be tiered based on severity and intensity, identifying vulnerable groups, ecosystems, and sectors. These programs should be revised regularly to incentivize adjustment to evolving extreme events. This should take place on different levels including farm level, sub-catchment, basin, and national levels.

Case Study: Jordan Decoupling Water Consumption From Economic Growth
The Third National Water Master Plan (NWMP-3) implemented by Jordan and GIZ exemplifies decoupling water consumption from economic growth. It incorporates all critical factors impacting water consumption, including future projections and their impact on water supply security, thus addressing overall economic and social resilience. NWMP-3 integrates climate change impacts into strategic planning and details the analysis of water supply and demand at the municipal level, which identifies demand gaps and guides evidence-based strategic investments in the water sector. The utilization of treated wastewater projects has not only enhanced water resilience but also economic resilience, specifically in the areas of food security and employment. Increasing water availability can contribute to food and water price reduction and create opportunities for small-scale farmers.

Mode 2: Risk identification and reduction procedures can make water-based resilience a consistent, reliable outcome

Evaluate and address water risks within the entire scope of actions, reactions, supplies, and processes, as significant water risks can extend beyond direct physical facility risks.

1. Utilize simulations and modeling to stress test water commitments against a range of climate and non-climate stressors impacting various economic sectors (action and reaction). This approach will help in identifying synergies and tradeoffs, such as those between energy and agriculture.
2. Analyze the water distribution system (supply), in addition to the hydrological basin to fully understand water risk and change. The analysis should encompass water disposal practices, interactions with groundwater as well as the concept of intensity of water embedded in the production of goods and food products.
3. Mainstream and incorporate climate risk assessments (process) in early phases at the project-level. This can address uncertainties in the water cycle.

Case Study: Reinventing Drought Policies in the Netherlands
The Netherlands, despite its robust flood management systems, is facing significant challenges in adapting to water shortages. Economically, droughts present a mixed effect, where incidental droughts have positive economic effects for some sectors such as shipping and agriculture due to temporary increases in prices for products and services. However, prolonged dry conditions also have many indirect consequences everywhere from urban areas to peat meadows to nature reserves. For instance, the 2018 drought in the Netherlands had an estimated economic impact ranging from €450–2080 million. With future drought risks projected to escalate, the potential economic consequences could reach €611 million by 2050. The second Delta Programme reinvented its policy approach to implement structural reforms. Important mechanisms in the context of adapting to water shortages included: 1) emphasizing the urgency of adapting to water shortages, 2) facilitating the participation of a broad range of actors, 3) creating a seedbed for promising ideas, and 4) achieving joint fact-finding to establish consensus and build upon existing institutions. These mechanisms can inform the creation of adaptation pathways that provide insights into options, taking into account lock-in possibilities, and path dependencies while incorporating risks and their impacts to support decision-making on long-term adjustments. In conclusion, the Netherlands is actively integrating water scarcity issues into its broader approach to managing flooding and inundation.

Mode 3: Strategies for sustainable water management can balance efficiency, diversity, and resilience

In response to increasing climate extremes impacting water availability, it is essential to not only address current challenges but also proactively plan for unprecedented events. This entails planning for multiple futures, including quite different credible extreme scenarios, for long-term planning.

1. Reevaluate the assumption that water use efficiency is fully aligned with adaptation and resilience and paired with adequate regulations to prevent inefficiencies.

For example, Jevon's paradox shows how improvements in technical efficiency in irrigation water systems often lead to net increases in water use, especially if the costs associated with delivery or consumption fall with increased efficiency.

2. Diversify water sources through incorporating unconventional water sources like treated wastewater reuse, desalination, and water recycling, alongside efficiency measures such as leak detection and remediation. Invest in land-use planning for watershed storage improvement through reforestation, afforestation, protection of natural areas, and combating soil degradation to enhance "green" water availability and groundwater replenishment.
3. Emphasize flexibility in infrastructure and investment planning in the context of climate and non-climatic uncertainties to be cost-effective.
    a. Plan for redundant water sources in critical infrastructure and encourage diversity in essential water-sensitive sectors, like water and energy utilities, to adapt to changing climate conditions.
    b. Include contingency planning for areas depending on a single and vulnerable resource and consider remedial action plans for surface and groundwater potentially at risk of contamination in highly built-up areas.
    c. Integrate the value of undeveloped spaces for flood mitigation and groundwater recharge into land-use planning and policy. This will promote resilience through real estate valuation, zoning, and urban planning, preserving the environmental functions of these areas in future development decisions.

Case Study: Expanded Water Supply Systems in Namibia
The case of Namibia's capital, Windhoek, highlights the country's vulnerability to climate change, particularly regarding water availability. To address this, a Managed Aquifer Recharge (MAR) project was implemented in 2006 — an approach determined to be the most cost-efficient option compared to other alternatives. The MAR scheme serves as a supply backstop to ensure water supply during prolonged droughts. Its integration as an alternative water supply contributes to the city's water security and resilience. This supply scheme has the advantage of low capital and operational costs for conveyance as it is located close to the demand area. It can yield an economic internal rate of return (IRR) of approximately 94 percent when integrated with a desalination scheme option, while the integration with the Okavango River transfer scheme can yield an IRR of around 68 percent. Incorporating resilience in planning, investment design, and operations can be incentivized through results- and performance-based financing, which may require a shift in investment strategy in response to unexpected conditions. To allow for future operation of the scheme, it is expected that the beneficiaries co-finance the operation over the economic lifespan of the project with US$ 115 million for operational costs and capital replacement over 30 years. This can be done via water expenses, which can be adopted according to the amount and usage.

Mode 4: Resilient governance frameworks can ensure that water tradeoffs are transparent and clear, enabling decision-makers and stakeholders to anticipate rather than simply react to risks

Government expenditures and revenues are affected by climate-water risks, which can manifest as both explicit and implicit contingent liabilities (OECD, 2022). Building resilience requires shifts in the ways institutions operate and how they define and implement policies, along with necessary shifts in the structure of regulatory frameworks to incentivize and limit certain actions. Resilient governance frameworks can provide policy-makers with systematic approaches to assess and proactively address risks and evaluate tradeoffs.

1. Water is a human right. Therefore, resilience systems need to assess the distributional impacts as well as how climate shifts may alter equity over time and guarantee water security for all. For instance, flood risk may be increasing for less wealthy communities or water scarcity may place a higher burden on women and girls for WASH.
2. The integrity of natural hydrological systems is important to value explicitly for infrastructure systems. Including the use of governance, regulatory, policy, and legal agreements that allow for the formal integration of these systems as a public good (e.g., Peru's new NBS laws) can bolster resilience.
3. Explicit consideration of water sharing and allocation is an essential tool for decision-makers in finance, agriculture, food processing, manufacturing, energy, and data. Traditional volumetric agreements and regulatory systems in share-based allocation systems often prove brittle during climate transitions in adapting to high variability in water availability. In contrast, non-volumetric agreements may be more effective and functional in high variability systems.
4. The updating of financial and economic regulations and incentives should be overseen by independent groups to ensure equity, transparency, and the inclusion of underrepresented groups, for example frontliners and NGOs working with indigenous communities.

Case Study: Proposal for Coordinating Investment Across Stakeholders in Afghanistan

Afghanistan, a country with ongoing political instability, faces severe water scarcity due to climate change, conflict, and poor institutional management. Despite receiving over US$ 4 billion in ODA financing over the last 20 years, Afghanistan still requires a significant investment of more than 6 percent of its GDP to address flood risks. The investment gaps are significant, and the recent Taliban takeover has exacerbated the humanitarian crisis in the country. To achieve economic resilience via water resilience (under the de facto authorities), the international community, especially bilateral and multilateral donors, must coordinate a comprehensive approach that addresses the root causes of water insecurity and economic fragility in the country. The fastest path could be creating an Afghanistan Water and Climate Emergency Working Group and an Afghanistan Water and Climate Emergency Fund under the Special Trust Fund for Afghanistan (STFA) by the United Nations. Creating a dedicated setup to centralize and ring-fence finance would provide proper focus and attention to Afghanistan's water and climate change emergency.

Mode 5: Financial analytical tools and incentives can guide technical decision-makers to see water beyond individual sectors and projects and integrate resilience early

To compensate for the uncertainties due to climate change and to stimulate adaptation investments, it is vital to establish economic instruments and adopt financial analysis tools. These tools are designed to create socially appropriate incentives and guide decision-makers in viewing water management from a broader perspective, transcending the limitations of individual sectors and projects.

1. Strategic use of subsidies for resilience and equity is essential to ensure that resilience is supported without inadvertently increasing demands. The goal is to promote greater resilience and ensure equity.
2. Implementing pricing schemes for water services can serve as a powerful incentive to promote water resilience. This approach can encourage the protection of resources, the adoption of nature-based solutions, and the comprehensive utilization of non-conventional water supplies.
3. Cost-benefit analysis should consider indirect benefits and costs. Incorporating both quantitative and qualitative measures is essential.
4. Discount rates should reflect risk sharing, future uncertainty, and long-term benefits. This is true for financial institutions as well as at the national level.
5. Aligning operational lifetimes with financing periods can help reflect long-term risk sharing with lenders and investors and incentivize long-term risk assessment.

Case Study: A Cap-and-Trade and Cost Reflective Pricing Mechanism in Australia's Murray-Darling Basin

The Murray-Darling Basin (MDB) has faced severe water scarcity, prompting a series of reforms to improve water management. Historically, the MDB has faced severe water scarcity. The 1982–1983 drought was followed by the Millennium Drought from 2002 to 2009. The Millennium Drought led to substantial economic losses including a 99 percent reduction in production of rice and an 84 percent decline in cotton production, alongside significant job losses. To address these challenges, the government introduced reforms that included integrated management of water resources, buybacks of water entitlements for the environment from irrigators and their assignment to the Commonwealth Environmental Water Holder (or state equivalents), as well as extensive investment in more productive irrigation systems. Two key policy instruments that have been instrumental in improving water resilience and economic resilience in the MDB are cap-and-trade mechanisms and cost-reflective charges for infrastructure and services. Cap-and-trade allows for the efficient allocation of water by enabling the trading of water entitlements. This takes place through the creation of water markets coupled with effective management of the allocated water systems. Cost-reflective pricing entailed the National Water Initiative (NWI) requiring independent economic regulators to have a role in the reviewing or setting of water services' prices. This encouraged efficient service delivery by applying rigorous scrutiny to operational and investment decisions. It facilitated consistent and improved planning, increased the transparency of decision-making, and reduced the risk of political interference in price-setting processes. Cost-reflective pricing is now used for urban water supply and wastewater management, and for major irrigation schemes.

Mode 6: Tailored finance can help pay for the additional costs of adaptation and resilience, while resilient regulatory frameworks can make climate-water risks visible to investors and the public

Latest trends show an increasing number of financial resources mobilized by private and public sectors. These resources are allocated towards initiatives focusing on transformations — for example, clean energy transition, digital transformation, and the extended use of nature-based approaches to provide services for cities and rural areas. These and other fields have identified resilience as a new technical and operational framework. This will indeed facilitate moving beyond reducing climate risk by addressing specific threats, while also allowing for streamlining of practical approaches that can better prepare our communities, economies, and ecosystems for a broader spectrum of both known and uncertain changes.

Climate finance has been front and center in the global agenda for the past few years. Countries, international organizations, and philanthropies have been allocating substantial pledges to address the soaring need for funds. Nevertheless, these commitments fall short compared to the real needs of at a global scale — particularly for developing countries. Middle- and low-income countries are not only grappling with climate change challenges, but the current distribution of funds also tells a different story. The substantial majority of climate finance, almost 90 percent, is allocated to mitigation, of which only 3 percent goes to developing nations (Naran et al., 2022). This disparity further highlights the financing challenges facing water adaptation projects, essentially being limited by current climate financing mechanisms and capital procurement processes (IWRM, 2022). Water resilience projects have received at most 5 percent of all labeled climate finance (OECD, 2021).

1. Leveraging climate finance mechanisms to ensure that all water investments incorporate de-risking and resilience components is essential for scaling.
2. Financial institutions should incorporate performance-based financing and incentivize the incorporation of resilience in planning, regulation, investment design, and operations — including the need to shift investment strategies if unexpected conditions arise.
3. A more diversified insurance system should be developed and tailored to address multifaceted impacts, stresses, and shocks realized because of climate change. For example, this can include the establishment of fast-access insurance pools which provide rapid assistance for following climate-related disasters as well as parametric insurance for predetermined thresholds/impacts.
4. Risk pools, risk sharing, and insurance and credit rates should be regularly updated to anticipate plausible future impacts. Proactive negotiations should be initiated with commercial credit institutions, as well as insurance and reinsurance programs, to ensure their sustained operation and commitment in the face of evolving climate challenges.

5. Consider partnerships as a meaningful tool to support the protection and sustainable use of freshwater ecosystems and thus essential for water and economic resilience.

Case Study: Facilitating Private Sector Investment in Water Resilience to Meet Public Sector Goals in Chile

In the 1980s, Chile implemented free-market economic changes privatizing the country's water and sanitation services. As a result, private entities are now responsible for delivering these vital services to the public. Privatization has brought numerous benefits to the water sector in Chile, including increased efficiency, investment, and improved services for customers. Private companies have the incentive to provide high-quality services to remain competitive and profitable, leading to better infrastructure, water quality, and service reliability. They invested US$ 2.3 billion in wastewater treatment between 2000 and 2017, enabling Chile to achieve treatment levels comparable to more advanced countries. The Chilean private sector's role in promoting water resilience goes beyond providing water-related services. It includes assuming responsibility and leadership for investments that prioritize sustainability and environmental protection. Additionally, it includes improving the efficiency of water resources and communicating responsible use protocols to their consumers.

Mode 7: Investing in capacity and training can create durable, permanent institutional changes and fuel a reorientation towards resilience

Structural reforms in water management must be complemented by dedicated efforts in capacity building and raising awareness.

1. Identify and address the eco-hydrological "transition costs" for communities, occupational sectors, and livelihoods that are likely to be more sensitive to changes in water availability.
2. Engage in multi-stakeholder action for enhanced resilience, for example, by promoting a water-stewardship approach.
3. Conduct training and outreach for climate-adjusted industries (e.g., resilience extension services to enable broader food system resilience).

Case Study: Diversifying Existing Livelihoods, Organizing Institutions, and Infrastructure in the Inner Niger Delta

Wetland systems, such as the Inner Niger Delta (IND), have significant economic and social value at local and national levels in the Sahel. The economy of the IND is based on farming, fishing, and pastoralism, and it supports a diverse range of livelihood strategies, including seasonal migration. The annual cycle of flooding and de-flooding is a critical feature of the IND's regional economy, which requires new water infrastructure to be "conflict sensitive" (Wetlands International, 2019). Climate change is disrupting current practices and requires new strategies to increase food and energy production and ensure water security. The current strategy in the IND primarily focuses on large-scale irrigation and hydropower, which will bring benefits but also risks, including changes in the flood pulse, diminished livelihoods, biodiversity loss, and increased instability. Therefore, safeguarding and optimizing the role of the IND should be central in future planning and investment. Measures are needed to ensure that water-related investment, strategy, and policy maintain critical natural systems as part of development solutions, rather than risking depletion and creating risks and problems.

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