WHAT THE FUTURE HAS IN STORE

A New Paradigm for Water Storage

Overview for Policy Makers

INTRODUCTION

In 2018, Cape Town, South Africa, was in striking distance of catastrophe, making international headlines as 4 million people in a major modern metropolis stood weeks away from one of the largest drought-induced municipal water failures in recent memory.

Through extraordinary emergency conservation measures, Cape Town avoided what became widely known as "Day Zero" (Harding 2021). But the fact is, prior to the crisis, the city had a water storage system that was fit for purpose for decades. It was only when faced with the effects of population growth and climate change that it teetered on disaster.

Like many areas of the world, Cape Town is experiencing increasing climate extremes, from drought at one end of the spectrum to intense flooding at the other, its 2022 events stretching the city's stormwater infrastructure beyond capacity, threatening human life, and causing massive economic damage. Over the last two decades, at least 1.65 billion people globally were adversely affected by floods—an increase of 24 percent of people exposed compared to previous decades (Browder et al. 2021; Tellman et al. 2021; CRED and UNDRR 2020).

Cape Town's gap between the amount of water needed and the capacity of available storage to supply it in the drought periods and to lessen flood impacts in wet periods is a graphic illustration of what is today an international crisis: **a global water storage gap**. Natural storage is declining, the amount of built storage has declined, and what is available is aging and waning, all while the global population—doubling in the last half-century—generate a constantly increasing demand for water and commensurate water storage.

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February 2023

Exacerbating the water storage crisis is climate change, its prognosis worsening each year and threatening to overwhelm governments' capacity to put measures in place to protect their populations' health and welfare. Nowhere is the impact of climate change more visible than in water. A significant increase in storage is required to manage escalating hydro-variability, including floods and droughts, to provide for increased water demands due to higher temperatures, and to underpin progress in food and energy security.

The water storage gap is a shared global challenge. Most freshwater storage on earth is in nature, making nature a large part of the solution. Wetlands, aquifers, lakes, soil, and other natural storage need to be recognized as the assets they are, protected and managed to better meet storage needs. In addition, dams, tanks, and other built systems allow water managers vital control, compensating for changing water availability during wet and dry seasons, mitigating the impacts of floods and droughts, and providing essential services including clean energy, transportation, irrigation, and water supply for drinking and industry (figure 1).

Together these make up a dense web of natural, built, and hybrid water storage—but policy makers and even water managers rarely recognize and manage it as a system. Most often, storage is evaluated, designed, developed, and managed as independent facilities for specific stakeholders, resulting in arrangements that are unsustainable, inefficient, and not sufficiently resilient to meet the challenges of the twenty-first century.

What the Future Has in Store: A New Paradigm for Water Storage (World Bank 2023) is an urgent appeal to global and national leaders to begin championing smart storage that meets a range of human, economic, and environmental needs. Closing storage gaps will require policy and decision-makers to bring together a range of economic sectors and stakeholders, both public and private, to develop and drive multi-sectoral solutions that address the water storage gap holistically, effectively, and efficiently. Done right, **a new paradigm for water storage** will create a stronger foundation for sustainable development and climate action and resilience, paying dividends for populations, economies, and the planet, through years and generations to come.

THE INCREASING IMPORTANCE OF WATER STORAGE

Life as we know it depends on freshwater storage. Storage enables vital services such as water supply, sanitation, and irrigation, which in turn underpin human health, welfare, and food security. Water stored for hydropower not only produces clean energy directly, but also stores energy for when it is most needed—allowing increased use of variable solar and wind energy. River or canal transportation often relies on water storage to provide year-round accessibility for bulk goods carriers.

Water storage provides three major services (figure 2) that support economic growth, people, and the planet: (a) it improves the availability of water; (b) it reduces the impacts of floods; and (c) it provides a variety of services for energy, transportation, and other sectors by regulating water flows.

Water storage is becoming progressively more important as a vital tool for adapting to climate change. Climate change means changes in water, increasing variability and water extremes and changing the total water available and increasing water needs. Because climate change is bringing less predictable and more variable precipitation, it makes the provision of everyday services such as reliable urban water supply more difficult, farmers less productive, and discourages economic investment and job creation. Water storage provides a mechanism to offset some of the hydrological changes brought about by

The New Paradigm for Water Storage ***calls for developing and driving multi-sectoral solutions to the water storage gap, taking approaches that integrate needs and opportunities across the whole system, including built and natural storage.***

Natural storage is declining, the amount of built storage has declined, and what is available is aging and waning.

climate change by improving water availability and reducing the impact of floods.

Storage makes an important contribution to climate change mitigation by producing and enabling renewable energy. Hydropower will play a key role in climate change mitigation efforts, with the International Renewable Energy Agency (IRENA) estimating that 1,300 GW of new capacity are needed to decarbonize the energy sector, meaning that investment in hydropower production will need to double (IRENA 2021). Hydropower storage enables power system operators to balance other more variable renewable energy sources such as wind and solar power in the grid (IRENA 2020), although care and attention to how storage is operated must include reduction of greenhouse gas (GHG) emissions from drawdown areas. Natural storage, such as wetlands and well-managed watersheds, can be consistent with soil carbon sequestration, an emerging opportunity to advance climate mitigation (Nahlik and Fennessy 2016; Ontl and Schulte 2012). In other areas, new water management techniques may need to be adopted, such as improved reservoir management and improved in-field water storage management—for example, alternative wetting and drying in paddy production, to minimize GHG emissions associated with water storage.

WHY NOW? THE GROWING GLOBAL WATER STORAGE GAP

Nature provides the vast majority—over 99 percent—of freshwater storage (McCartney et al. 2022). The rivers and lakes we rely on are filled by rainfall in the watershed. Water needed for agriculture, forests, and the environment is stored in the soil as soil moisture, and this soil moisture can contribute to future groundwater and surface water flows in streams and rivers. For daily survival, more than half of the global population rely on groundwater, water that is stored underground by nature and replenished—or not—by complex hydrological processes (UNESCO 2022). Nature also buffers against floods, slowing runoff and absorbing excess water in soils, vegetation, wetlands, and aquifers. The extent of nature's role in flood protection is becoming increasingly clear as we degrade it, with 23 of 34 areas of the globe experiencing reductions in freshwater storage (Rodell et al. 2018).

Built storage allows water managers more control over water resources. Reservoirs, sand dams, tanks, and other built systems provide water storage where it is needed and can be designed to provide the service that stakeholders require, for example, improving local water availability in the dry season or generating hydropower during times of peak demand. Built systems often provide a much higher degree of control than natural systems, enabling "on demand" services that create more certainty for users, making them easier to finance because of improved cost recovery. Type and sizing of built storage can be tailored to specific climate or location needs by varying design or system selection to minimize losses and increase compatibility with the economic and local community needs. However, built water storage projects can also have significant negative impacts, sometimes disproportionately on the poor and the environment, including biodiversity. Storage options need to be selected to avoid impacts, and negative impacts need to be carefully mitigated and managed across a range of scales, from the project site to the basin scale, sometimes crossing international boundaries.

Multiple forms of water storage—built and natural—usually combine into storage systems, where elements work together to provide the services people rely on (figure 3). For example, floodplains and wetlands combine river channels and soil storage, providing storage for floods and water for drier periods; natural watersheds contribute to sustainable dam operations; managed aquifer recharge sites harness natural and built infrastructure

FIGURE 1 Water Storage Types

Source: Original figure for this publication.

FIGURE 2 **Core Services of Water Storage**

IMPROVES WATER AVAILABILITY

Around the world, human settlements and industries of all sizes do not have sufficient water storage accessible to meet the growing water demand from people, farms, and businesses during increasingly severe and lengthy droughts. Over the past 20 years, 1.43 billion people were adversely affected by drought (Browder et al. 2021). Cities like Chennai, India, and Mexico City, Mexico, have made news as their water supplies ran short. Even areas with well-developed storage infrastructure can see their reservoirs running low, like the Colorado River in the United States, which, at the time of writing this report, was experiencing a historic mega drought, devastating the water supply for 40 million people and vast agricultural areas. As a result of water scarcity, some countries can experience an up to 6 percent reduction in growth (World Bank 2016). The negative effect of water scarcity on the poor can last generations.

Water storage improves the availability of water during drier periods by changing its distribution across time and space, thereby improving the water supply for cities, crop productivity for farmers, and reliable services for businesses. During dry periods, water storage done right has positive impacts on local GDP (Damania, Desbureaux, and Zaveri 2020), especially in developing countries, notably through increasing the resilience of agricultural production and boosting food security (Duflo and Pande 2007; Strobl and Strobl 2011). Firms with reliable water supply show higher performance than those with less reliable supply, especially in the informal sector (Islam 2019; Islam and Hyland 2019).

REDUCES FLOOD IMPACTS

In the other extreme, the destructive power of floods is increasing. By 2030, projections suggest an additional 180 million people will be directly affected by flooding (Tellman et al. 2021), with devastating effects. In the United States, 2019 riverine floods in the central and southern states caused $17 billion in damages, compounded by an additional $6.6 billion in damages due to storm surge-induced coastal flooding (TNC 2020). Flooding also comes at a high social cost, as it negatively impacts health and human capital accumulation, thus diminishing people's welfare and future productivity (Maccini and Yang 2009; Nguyen, Le, and Vo 2021). The poor and vulnerable are disproportionally affected.

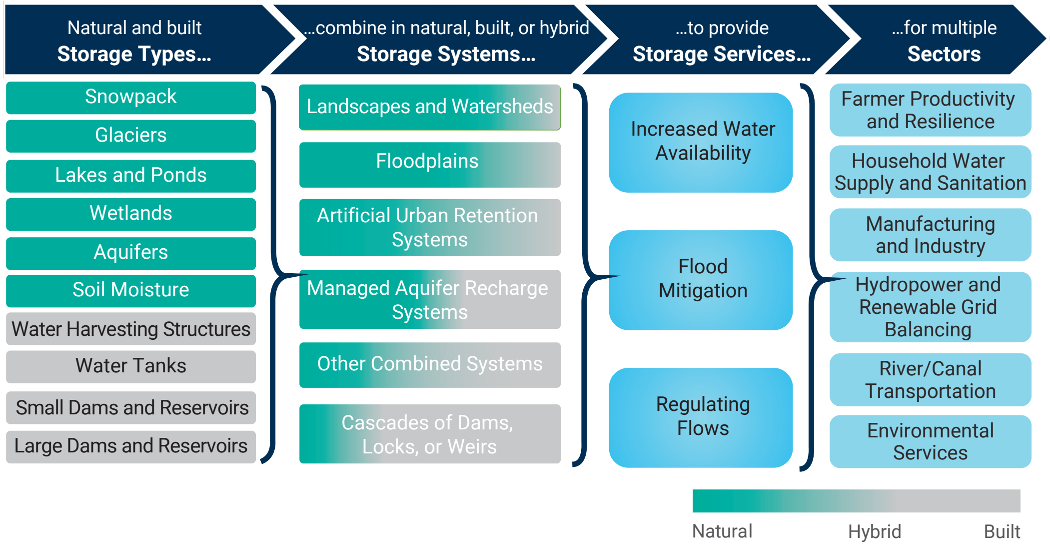
Water storage can mitigate the impacts of floods, reducing what can be enormous economic and social costs. It is estimated that the world's current dams, if operated for flood control purposes, could reduce the number of people affected by flooding by 12.9 percent under a high GHG emission scenario (RCP 6.0) and by 20.6 percent under a more optimistic climate change scenario (RCP 2.6) (Boulange et al. 2021). Floodplain restoration and other natural control flood measures can result in a significant return, measured in avoided losses equal to five times the amount invested in restoration (TNC 2020).

REGULATES WATER FLOWS

Storage is a tool for regulating water levels to suit a specific economic or societal purpose, such as maintaining navigation, recreation, or the ability to generate hydropower. Hydropower—which currently provides more electricity than all the other world's sources of renewable sources combined (IEA n.d.)—can benefit from storage through increased water availability during dry periods, through higher water levels for increased power production, and through the regulation of downstream releases for environmental reasons. Upstream storage on a river can be used to regulate water levels downstream to allow sufficient clearance for passage of vessels for navigation. Storage can support reservoir or downstream water levels needed for boating, whitewater rafting, fishing, swimming, or other recreational purposes. Finally, regulated surface water levels can be used strategically to curb saline intrusion into groundwater, thus preserving the quality of groundwater to overcome water availability challenges.

Source: Original figure for this publication.

FIGURE 3 **Different Types of Storage Combine in Systems to Provide Vital Services**



Source: Original figure for this publication.

to slow water flows in parts of a watershed to significantly increase the amount of rainwater that filters into groundwater. Several smaller systems may combine into larger systems; for example, the flood vulnerability of a city will be influenced by surrounding systems of land use, groundwater recharge, and floodplains as well as local flood mitigation measures.

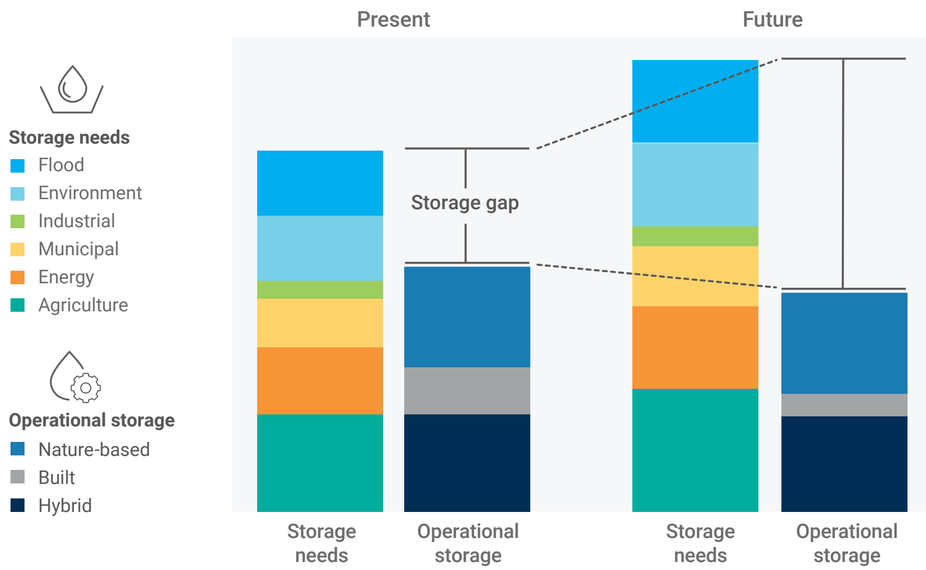
The world is already experiencing a water storage gap. Globally, the water storage gap—the difference between the amount of water storage needed and the amount of operational storage (natural and built) (figure 4)—is growing (GWP and IWMI 2021). Over the last 50 years, the supply of water storage has decreased as freshwater storage declined by around 27,000 billion cubic meters (McCartney et al. 2022) due to melting glaciers and snowpack and the destruction of wetlands and floodplains (figure 5).

Additionally, the volume of water stored in built storage such as large dams is also under threat as sediment fills the useful storage space in reservoirs, and structures age faster than the pace of rehabilitation or new construction (Annandale, Morris, and Karki 2016) (figure 6). Meanwhile, the need for more storage has increased due to the vast changes the world has experienced, including a global population that increased from 1 billion in 1800 to 7.8 billion in 2020 and economic growth of the twentieth and twenty-first centuries that has translated into rapidly increasing water demand, all while growing climate variability increases floods and droughts.

Ultimately, all water storage gaps are local, measured in simplest terms by supply vs. demand. In any system, storage demands occur at varying scales, times, and volumes, with requirements related to reliability, vulnerability,

> Closing the global water storage gap is a shared challenge. A conceptual shift in thinking, anchored in an integrated, systemic approach, is imperative.

FIGURE 4 **The Growing Storage Gap**

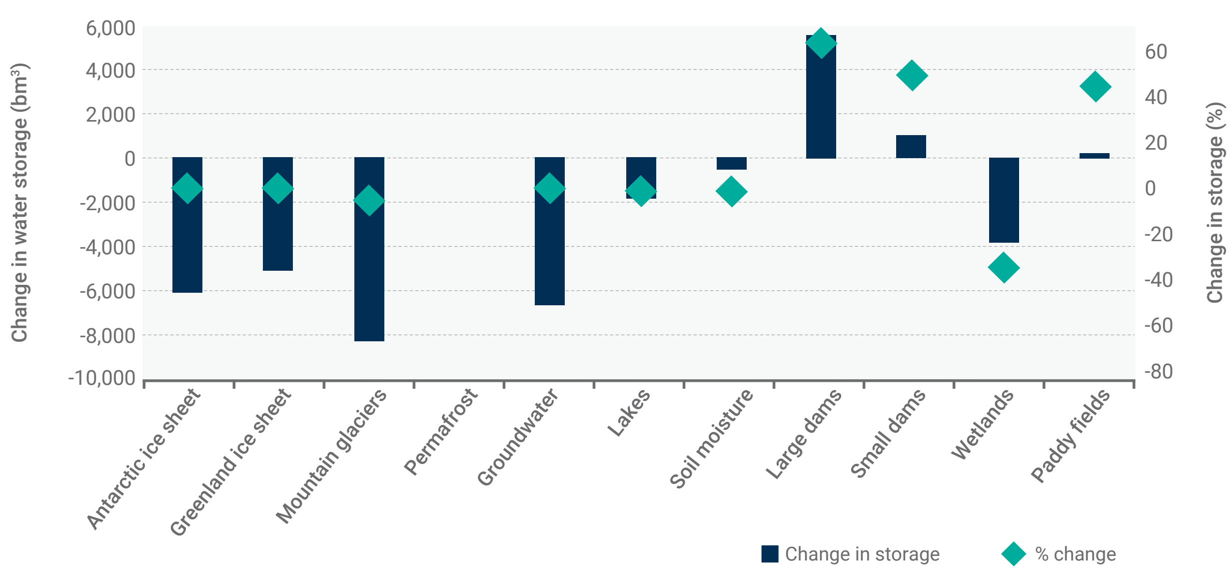


Source: Adapted from GWP and IWMI 2021.
Note: Amounts of storage needed and operational storage are stylized estimates.

resilience, and control. On the supply side, availability depends on natural, built, and hybrid storage, with combinations offering a variety of advantages in terms of scale, timing, volume, and service.

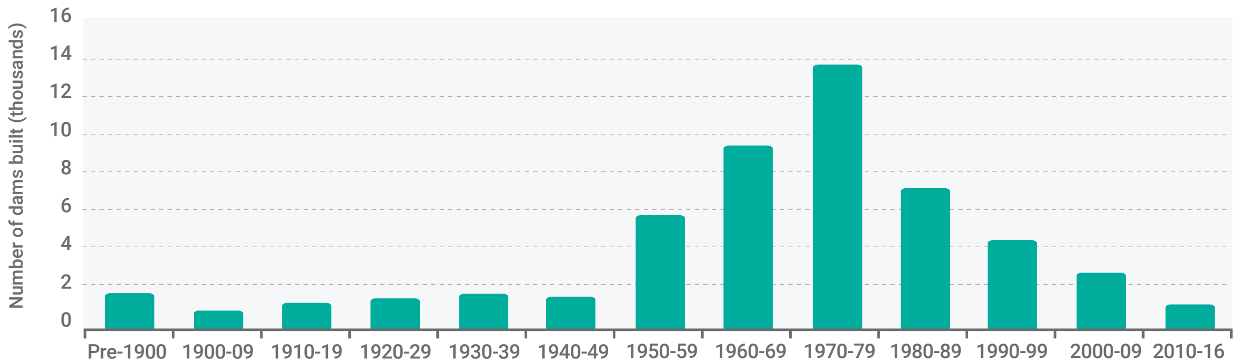
For any given location, the practical responses to addressing storage gaps should also consider other non-storage options, for example, water demand management, as part of a broader approach to securing water resources. As illustrated in figure 7, perceived storage needs may be reduced by storage alternatives such as demand reduction measures (e.g., leakage reduction or demand-control pricing) and alternative supply options (e.g., desalination or treated wastewater reuse). As a result, the

FIGURE 5 **Changes in Water Storage, by Type, 1971–2020**



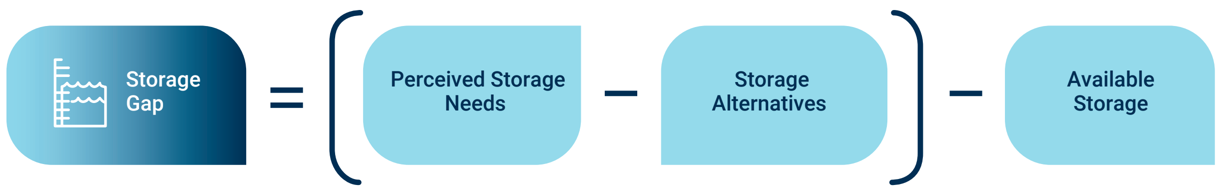
Source: Adapted from McCartney et al. 2022.

FIGURE 6 **Development of Dams over Time**



Source: Wishart et al. 2020 based on ICOLD World Register of Dams.

FIGURE 7 **Water Storage Gap**



Source: Original figure for this publication.

size of the storage gap may differ significantly over time even if the amount of storage stays the same. Despite the local nature of water storage gaps, given that the river basins and the groundwater basins are transboundary, for many, addressing the storage gap will require working across borders.

CHALLENGES WITH CURRENT APPROACHES TO WATER STORAGE

Planning, building, and managing water storage is inherently challenging, which perpetuates the storage gap. While some of these challenges are technical, many are related to insufficient governance or protection of water systems, short-term financial and administrative incentives, limited prioritization of storage, misalignment of service needs and storage opportunities, and lack of clarity and communication around a broad set of stakeholder interests and needs.

Limited recognition of the web of intersectoral, natural, and built water storage and failure to manage it as a system often result in overreliance on built storage, overlooking the value of natural storage. While built storage is generally understood to be providing direct services to people, natural storage is often invisible or taken for granted. Different types of storage are often developed (frequently, built storage) or degraded (both built and natural storage) in response to various needs or pressures, without full consideration of how natural and built storage can be managed and operated as a system to greater benefit.

In addition, approaches to scaling up storage can suffer from the following major challenges:

- ***A drive for new storage often eclipses opportunities for making better use of existing systems through rehabilitation, reoperation, and retrofitting.*** Short-term financial and political incentives often motivate development of new storage without full consideration of options that would increase services provided by existing natural and built storage.
- ***Multiple competing storage systems serve different stakeholders with different services, leading to uncoordinated development or releases from built storage and reduction in total benefits.*** In many

cases, storage is developed or operated to maximize a single benefit stream for a single set of stakeholders, whereas the same storage could provide a broader range of benefits to more communities.

- ***Costs and benefits and risks and uncertainties are not always well understood in advance of investment decisions.*** Large-scale interventions in the water cycle have large social, environmental, and economic consequences and are subject to significant financial and technical uncertainties. Negative impacts on people and the environment caused by storage must be minimized and mitigated with an eye toward distributional equity. Properly understanding costs and benefits in advance of investment decisions can be time-consuming, expensive, and difficult.
- ***Insufficient maintenance of existing storage is driven by several factors*** including insufficient attention to preserving natural storage, sedimentation of built storage, and poor operation and maintenance.
- ***Current storage is unable to meet growing risks of climate change or protect the value of investments.*** Climate change may mean that storage systems need to meet new performance requirements to provide the same services and need to be altered for safety concerns, for example, to handle increased floods.
- ***Policy and institutional measures are often lacking.*** Without these, water storage runs the risk of limited sustainability, and in some cases, may be counterproductive; for example, large new dams might increase water consumption beyond what had been anticipated as new supplies become available.
- ***Overreliance on storage when there may be other, more efficient solutions*** such as demand management or valuation or pricing of water; supply-side alternatives such as desalination or treated wastewater; or non-water alternatives to energy and transportation.

> Failure to manage water storage as a system often results in overreliance on built storage, overlooking the value of natural storage.

There is no simple solution to these complex challenges, but focusing on the underlying reasons for them provides a path to better approaches. Addressing them involves avoiding fragmented approaches and instead considering multiple types of storage that rely on the same water, multiple services required within a system, and the storage- and water-related needs of multiple users that share the same water. In short, a more integrated approach is required.

THINKING DIFFERENTLY: A NEW PARADIGM FOR WATER STORAGE

More effective, efficient, and sustainable approaches to storage require us to think differently about success, as well as our approaches to developing, investing, and managing storage. This means applying the principles of integrated water resources management to enhance water security and incorporating conceptual shifts (table 1) that include an integrated approach that focuses on storage outcomes, integrating natural and built storage as a system, getting more from the current system, and managing risks through diversification.

An integrated approach (figure 8) can start with a systematic definition of the problem. Storage problems and solutions are scale- and context-specific: they can be national, or focused on a particular river basin, or a particular stakeholder such as a metropolitan area, industry, or community. Whatever the starting point, it is important to be able to define the problem with respect to the services and timeframes required, and to define the range of stakeholders with related needs. (The new Integrated Storage Planning Framework is available in detail, along with global case studies, in the main report, *What the Future Has in Store: A New Paradigm for Water Storage* [World Bank 2023]).

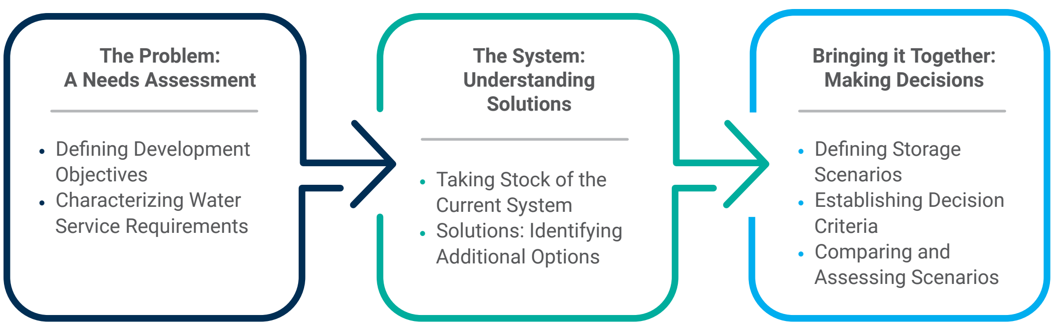
Clarifying core objectives and characterizing water service requirements for future investments provide the foundation for further work. Policy makers can help in this process by clarifying the criteria that measure

TABLE 1 Conceptual Shifts: An Integrated Approach to Thinking about Water Storage

TOPIC	FROM	TOWARDS
Defining success	Storage volumes	Storage outcomes—the services enabled by storage
Storage approaches	Built storage	Natural and built storage and their interactions
Storage management	Facility level	System level, working across institutions and borders
Storage development	New development	Getting more from current—through retrofitting, reoperation, and rehabilitation—and developing new
Risk management	Infrastructure development	Diversification of storage types across storage systems; selecting robust storage options given uncertainties in future water supply and demand

Source: Original to this publication.

FIGURE 8 Integrated Storage Planning Framework Stages



Source: Original figure for this publication.

success. This should include technical criteria such as levels of service reliability; social criteria such as likely beneficiaries of the service or potential negative effects on some people; environmental criteria such as potential ecosystem preservation or impacts; financial criteria such as cost and potential for cost recovery; and economic criteria such as overall returns to the economy and society.

An integrated approach requires a systems perspective. Water is shared among multiple stakeholders, and actions by one may well affect others. The hydrological system is the foundation of integrated storage planning and management, but there are also environmental, social, and economic systems that need to be understood and addressed within a systems approach to storage. This may include sectoral systems like agriculture, energy, transport, industries, and utilities, and various levels of jurisdictions, from local, city, and basin, to national and international systems.

The challenge is not "What is the next investment to make?" but rather "Which combination of investments and policies offers the most robust and resilient system for long-term storage?" This requires considering a broad range of options, starting with understanding the current storage system. Being able to model the interactions and performance of the current storage system can help determine whether more storage services can be extracted from it, as well as identify additional storage opportunities. Critically, it also helps to identify the range of stakeholders that currently depend on the natural and built storage within a system, and, therefore, who needs to be engaged in the process. Additional storage services can be gained from current storage or from adding new storage. Opportunities for increasing storage services are outlined in table 2.

Measures to fill the gap must be fit for purpose depending on the local conditions, as some countries may experience less pressure while others already

TABLE 2 **The 5 R's: Opportunities for Increasing Storage Services**

Reoperation	The modification of storage operations for improved management (efficiency gains), which might include changing the timing of water releases from controllable infrastructure to increased benefits, or adding additional benefit streams, such as flood control or minimizing storage losses from evaporation, etc. This may also include managing for synergies between different types of storage or creating new connections between existing storage so that they can be operated as part of a broader system.
Rehabilitation	The rehabilitation of storage—natural or built—to improve storage capacity or performance. Rehabilitation often means ecosystem and natural landscape restoration to its more natural state, including original capacity of natural storage. Rehabilitation can also extend the life of existing built storage capacity—through direct infrastructure works or through restoration of natural landscapes to reduce degradation of built storage—both of which may defer investment in new storage. Restoration of original capacity or slightly improved capacity could be achieved through addressing structural defects, sediment removal, increasing the flow rates of managed aquifer recharge sites, and environmental restoration of natural storage sites, among others.
Retrofitting	The upgrading or augmentation of capacity at existing storage facilities, and/or enabling new uses of the facilities. This could be achieved through raising the height of a dam or adding new hydromechanical or electromechanical equipment to serve different objectives or different customers to make overall gains in the value of storage services. Adding floating solar panels to existing hydroelectric projects, or adding hydropower generation to irrigation projects, are two examples.
Reform: Investing in institutions to manage storage better	In addition to physical investments in storage, policy makers need to invest in institutions that are required to better plan and manage storage. This includes institutional capacities to: • Manage the data, modeling, and planning systems required to develop smarter storage. • Enable and incentivize integrated planning, development, and management at multiple scales across multiple stakeholders. • Mobilize the finance and financial incentives that enable storage to be prioritized, planned, and managed in the broader public interest. Policy and institutional approaches that manage water allocation, improve the efficiency of services, price water services appropriately, and address social and environmental issues are all necessary complements to appropriate, sustained storage management. Land management, conservation, and protection measures are key requirements for maintaining or restoring natural infrastructure.
Raising New: Finding or developing additional storage	This involves exploring the full range of available storage types: natural and built; surface and subsurface; large and small; centralized and distributed. New storage might be built at a variety of scales or created in nature through different landscape management practices (e.g., accelerating aquifer recharge). New storage can also be designed to leverage or complement other parts of the system to make the whole greater than the sum of the parts.

Source: Original to this publication. The concept of the "5 R's" has been adapted from the Uncommon Dialogue on Hydropower, River Restoration, and Public Safety, Stanford Woods Institute for the Environment, 2020.

have significant water storage gaps that may worsen over time. Some locations may be able to meet needs through reoperating existing water storage infrastructure or institutional setup, to use existing storage more efficiently. For example, in Lake Mendocino, California, the US Army Corps of Engineers and other stakeholders are piloting new reservoir operating rules that will allow for improved flood management. Other systems may require a more comprehensive intervention to expand the volume of water storage available to provide the services stakeholders need. For example, Monterrey, Mexico, has been working to rehabilitate and expand natural storage upstream of the city through participatory catchment management programs to provide flood protection services for the city and its assets, in addition to raising new built infrastructure.

Finally, contextual and attitudinal shifts in thinking about integrated water storage planning can provide a range of benefits, from managing extremes, reducing risks, and increasing sustainability. An integrated and multipurpose approach can help treat floods as a water "surplus" that can be captured and stored for drier times (hydrological); it saves on infrastructure that could be multipurpose (financial and economic); and it serves the needs of several sets of stakeholders, or at least considers their needs in an integrated way (social). Additionally, by diversifying types and location of water supply, it can help reduce correlated risk. Finally, it can enhance sustainability. For example, carefully managing watersheds is not only important to reducing sedimentation of reservoirs, but also contributes to the total storage within the system. If natural storage continues to release water later into dry seasons, it extends the storage capacity of built storage over time.

A CALL TO ACTION ON WATER STORAGE

Given the growing risks of water insecurity around the world, particularly in the face of the climate crisis, our approach to planning and managing water storage must change.

Closing the global water storage gap is a shared challenge. Global, national, and regional stakeholders can no longer focus only on their own needs in isolation. A conceptual shift in thinking, anchored in an integrated, systemic approach to planning and managing water storage, against the backdrop of broader integrated water resource management, is imperative if we are to achieve sustainable, climate-resilient water storage solutions that sustain generations.

Policy makers and decision-makers have a unique opportunity to lead. By setting the criteria for success, advocating an integrated, strategic approach that begins with a rigorous definition of the problem, and prioritizing efficient solution outcomes that benefit the largest range of stakeholders, they all have key roles to play.

Ministries of finance and planning can incentivize joint planning processes across ministries, sectors, and jurisdictions to ensure that natural and built storage are effectively and efficiently serving the needs of the greatest number of stakeholders. If mechanisms for joint planning are not already in place, ministries can host or facilitate joint planning processes, or be a neutral arbiter if the political economy around storage requires one.

In terms of investing, ministries of finance and planning can ensure budget lines to maintain storage are in place—both for built and natural storage—so that the storage gap does not continue to grow unabated. They can support conservation of natural ecosystem functions and support the collection of additional data through hydromet networks and other studies to allow for better use of natural storage. They can both fund activities that increase the benefits from existing storage—including processes to consider storage reoperation, rehabilitation, and retrofitting—and invest in new small-scale and large-scale storage after verifying that choices are based on robust integrated planning processes that actively engage all stakeholders. Finally, they can require that water storage investment decisions consider financing lifetime operations and maintenance to preserve its functionality over time.

Line ministries, local governments, storage operators, and water users can champion the new paradigm by engaging in aggregated, integrated planning processes for current and future storage service needs, and evaluating the performance of current storage systems and the options for improving them. This is no small task. These actors play a fundamental role by helping clarify the service levels required and identifying the combinations of investments that might best meet those needs across natural and built storage and non-storage alternatives, including demand management. Vitally, they can capitalize on the opportunity to engage with multiple stakeholders who have an interest in storage services in an initiative that can be spearheaded by an institution with a mandate for joint planning if it exists (such as a basin organization or a water resources authority), or by concerned operators or users.

In terms of built and hybrid storage, line ministries, local governments, storage operators, and water users can assess what gains can be made through reoperating, retrofitting, and rehabilitating, as well as raising new storage. In natural storage, it includes recognizing its value, enabling conservation and restorage by establishing programs to strategically rehabilitate natural systems, and working to better understand natural storage dynamics through monitoring. Finally, they can advocate a lifecycle approach to storage planning and management, diversifying storage types and integrating and managing storage as a system, to reduce risk. (*See case studies in the main report for examples of water storage strategies employed internationally*.)

Lawmakers can mandate or incentivize joint planning for storage and broader water use, if such mechanisms do not already exist in the form of basin authorities or other joint planning bodies; they can allocate budget for a range of storage options across the 5 R's, helping overcome bias toward investing in new and built over improving current and green storage solutions; and they can institute appropriate legal measures for safety, maintenance, and operation to help ensure storage can deliver benefits long term.

Transboundary river basin organizations and their stakeholders can engage in or even lead joint planning processes to identify the shared benefits of cooperative, transboundary integrated water storage management and development, seek ways to engage jointly in risk reduction, and work to develop benefits and risk-sharing frameworks between riparian states.

Finally, **development partners and financiers** can convene and support multi-sectoral storage planning processes; they can invest in activities around the 5 R's that have had proper due diligence; and they can support countries to engage in transboundary planning processes around storage.

The actions required to implement the new paradigm for water storage are necessarily multifaceted, predicated by a thorough understanding of which combination of investments, activities, and policies offers the most robust and resilient long-term storage system solutions. It is challenging; but investing in storage as a system is an investment in economic resilience, social welfare, and the environment. *What the Future Has in Store: A New Paradigm for Water Storage* provides a framework for accelerating collaboration between economic sectors and public and private stakeholders globally, setting out a strategy for tackling and overcoming the storage gap and supplying the water and water security needed by communities worldwide.

For more information on how policy makers and decision-makers can help address the growing water storage gap and create a stronger water supply foundation for their communities, see **What the Future Has in Store: A New Paradigm for Water Storage (World Bank 2023).**

BIBLIOGRAPHY

Annandale, G. W., G. L. Morris, and P. Karki. 2016. *Extending the Life of Reservoirs: Sustainable Sediment Management for Dams and Run-of-River Hydropower.* Directions in Development, Energy and Mining. Washington, DC: World Bank.

Boulange, J., N. Hanasaki, D. Yamazaki, and Y. Pokhrel. 2021. "Role of Dams in Reducing Global Flood Exposure Under Climate Change." *Nature Communications* 12: 417.

Browder, G., A. Nunez Sanchez, B. Jongman, N. Engle, E. van Beek, M. Castera Errea, and S. Hodgson. 2021. *An EPIC Response: Innovative Governance for Flood and Drought Risk Management.* Washington, DC: World Bank. Available at: https://openknowledge.worldbank.org/handle/10986/35754.

CRED (Centre for Research on the Epidemiology of Disasters), and UNDRR (United Nations Office for Disaster Risk Reduction). 2020. *The Human Cost of Disasters: An Overview of the Last 20 Years (2000–2019).* Brussels: CRED; Geneva: UNDRR.

Damania, R., S. Desbureaux, and E. Zaveri. 2020. "Does Rainfall Matter for Economic Growth? Evidence from Global Sub-National Data." *Journal of Environmental Economics and Management* 102. doi:10.1016/j.jeem.2020.102335.

Duflo, E., and R. Pande. 2007. "Dams." *The Quarterly Journal of Economics* 122 (2): 601–46. doi:10.1162/qjec.122.2.601.

GWP (Global Water Partnership), and IWMI (International Water Management Institute). 2021. *Storing Water: A New Integrated Approach for Resilient Development.* Perspectives Paper, Colombo, Sri Lanka: IWMI; Stockholm, Sweden: GWP.

Harding, A. 2021. "Cape Town's Day Zero: 'We Are Axing Trees to Save Water.'" *BBC News.* November 10, 2021. Accessed May 20, 2022. Available at: https://www.bbc.com/news/world-africa-59221823.

IEA (International Energy Agency). n.d. "Hydropower." Accessed May 20, 2022. Available at: https://www.iea.org/fuels-and-technologies/hydropower.

IRENA (International Renewable Energy Agency). 2020. *Global Renewables Outlook: Energy transformation 2050 (Edition: 2020)*. Abu Dhabi: IRENA.

IRENA. 2021. *World Energy Transitions Outlook: 1.5C Pathway.* Abu Dhabi: IRENA.

Islam, A. 2019. "The Burden of Water Shortages on Informal Firms." *Land Economics* 95 (1): 91–107. doi:10.3368/le.95.1.91.

Islam, A., and M. Hyland. 2019. "The Drivers and Impacts of Water Infrastructure Reliability: A Global Analysis of Manufacturing Firms." *Ecological Economics* 163 (3): 143–57. doi:10.1016/j.ecolecon.2019.04.024.

Maccini, S., and D. Yang. 2009. "Under the Weather: Health, Schooling, and Economic Consequences of Early-Life Rainfall." *American Economic Review* 99 (3): 1006–26. doi:10.1257/aer.99.3.1006.

McCartney, M., W. Rex, W. Yu, S. Uhlenbrook, and R. von Gnechten. 2022. "Change in Global Freshwater Storage." International Water Management Institute (IWMI) Working Paper 202, IWMI, Colombo, Sri Lanka. doi:10.5337/2022.204.

Nahlik, A. M., and M. S. Fennessy. 2016. "Carbon Storage in US Wetlands." *Nature Communications* 7. doi:10.1038/ncomms13835.

Nguyen, M-H., D. P. Le, and T. T. Vo. 2021. "Vulnerability to Natural Disaster and Welfare Effect: A Case Study of Flood Risk in Vietnam's North Central Region." *Journal of Asian and African Studies* 56 (8): 1879–98. doi:10.1177/0021909621993499.

Ontl, T. A., and L. A. Schulte. 2012. "Soil Carbon Storage." *Nature Education Knowledge* 3 (10): 35.

Pokhrel, Y., F. Felfelani, Y. Satoh, J. Boulange, P. Burek, A. Gädeke, D. Gerten, S.N. Gosling, M. Grillakis, L. Gudmundsson, N. Hanasaki, H. Kim, A. Koutroulis, J. Liu, L. Papadimitriou, J. Schewe, H. Müller Schmied, T. Stacke, C-E. Telteu, W. Thiery, T. Veldkamp, F. Zhao, Y. Wada. 2021. "Global Terrestrial Water Storage and Drought Severity Under Climate Change." *Nature Climate Change* 11 (3): 226–33. doi:10.1038/s41558-020-00972-w.

Rodell, M., J. S. Famiglietti, D. N. Wiese, J. T. Reager, H. K. Beaudoing, F. W. Landerer, and M.-H. Lo. 2018. "Emerging Trends in Global Freshwater Availability." Nature 557: 651-59. doi:10.1038/s41586-018-0123-1.

Stanford Woods Institute for the Environment. 2020. *Uncommon Dialogue on Hydropower, River Restoration, and Public Safety*. Available at: https://woods.stanford.edu/research/hydropower-home.

Strobl, E., and R. O. Strobl. 2011. "The Distributional Impact of Large Dams: Evidence from Cropland Productivity in Africa." *Journal of Development Economics* 96 (2): 432–50.

Tellman, B., J. A. Sullivan, C. Kuhn, A. J. Kettner, C. S. Doyle, G. R. Brakenridge, T. A. Erickson, and D. A. Slayback. 2021. "Satellite Imaging Reveals Increased Proportion of Population Exposed to Floods." *Nature* 596: 80–6. doi:10.1038/s41586-021-03695-w.

TNC (The Nature Conservancy). 2020. "How Nature Can Help Reduce Flood Risks." Accessed May 20, 2022. Available at: https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/natures-potential-reduce-flood-risks/.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2022. *The United Nations World Water Development Report 2022—Groundwater: Making the Invisible Visible*. Paris: UNESCO.

World Bank. 2016. *High and Dry: Climate Change, Water, and the Economy*. Washington, DC.: World Bank.

World Bank. 2023. *What the Future Has in Store: A New Paradigm for Water Storage*. Washington, DC: World Bank.

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This publication received the support of the Global Water Security & Sanitation Partnership (GWSP). GWSP is a multidonor trust fund administered by the World Bank's Water Global Practice and supported by Australia's Department of Foreign Affairs and Trade, Austria's Federal Ministry of Finance, the Bill & Melinda Gates Foundation, Denmark's Ministry of Foreign Affairs, the Netherlands' Ministry of Foreign Affairs, Spain's Ministry of Economic Affairs and Digital Transformation (MINECO), the Swedish International Development Cooperation Agency, Switzerland's State Secretariat for Economic Affairs, the Swiss Agency for Development and Cooperation, and the U.S. Agency for International Development.

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Suggested citation: World Bank. 2023. *What the Future Has in Store: A New Paradigm for Water Storage—Overview for Policy Makers*. Washington, DC: World Bank.

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