Addressing Water-Related Disasters in an Era of Multiple Crises: Lessons from Global Responses to COVID and Climate Change

A Flagship Report for the High-level Experts and Leaders Panel on Water and Disasters

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This report was prepared through a joint collaborative action by international experts in support of the High-level Experts and Leaders Panel on Water and Disasters (HELP). This action was led by the Ministry of Infrastructure and Water Management of the Netherlands and coordinated by Deltares and the Alliance for Global Water Adaptation (AGWA). The views and opinions expressed in the document are those of the authors and contributing experts and do not necessarily reflect the official views, opinions, policies, or positions of HELP or any other hosting government or organization.

About HELP

The High-level Experts and Leaders Panel on Water and Disasters was convened at the request of the UN Secretary General's Advisory Board on Water and Sanitation in 2007. The ambition of HELP is to assist the international community, governments and stakeholders in mobilizing political will and resources. HELP will promote actions to raise awareness, ensure coordination and collaboration, establish common goals and targets, monitor progress, and take effective measures aimed at addressing the issues of water and disasters. Contact HELP secretariat for more information on the HELP activities (helpsecretariat@wateranddisaster.org).

Please cite the work as follows: Kaspersma, Judith, Alex Mauroner, Pan Ei Ei Phyoe, 2023. Addressing Water-Related Disasters in an Era of Multiple Crises: Lessons from Global Responses to COVID and Climate Change. HELP report

This report was prepared by joint collaborative action from international experts, coordinated by a **core team** consisting of:
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Introduction: Are We Prepared for What is to Come?

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Learning from Recent Water-Related Disasters

After unprecedented heatwaves in April to June 2022, Pakistan suffered a prolonged and intense monsoon that led to the country's worst flooding in a century with glacial lakes bursting, rivers breaking their banks, flash flooding, and landslides. The flood was caused by the exceptionally high rainfall but was exacerbated by the inability to retain (store) water in the catchment and the impeded capacity to evacuate the flood water.

Total damage and losses were estimated at more than USD $30 billion and recovery and reconstruction needs at USD $16.3 billion (ADB, 2023). At their peak, the 2022 floods inundated more than 30% of the territory of Pakistan, mainly in the Sindh and Balochistan provinces. The floods withdrew slowly as the capacity to remove water was affected by many factors. This caused widespread damage. In large parts of the country, assets and infrastructure were lost. A post-disaster needs assessment, funded by the ADB, put the total damage in 2022 at USD $14.9 billion, weighing disproportionally on vulnerable people, with extensive damage to housing, crops, and livestock. Of the 25 poorest districts in Pakistan, 19 were calamity-stricken. The need for rehabilitation and reconstruction in a resilient, "building back better" manner of existing assets is estimated at USD $16.3 billion.

In July 2021, severe environmental disturbance events occurred across Western Europe (predominantly in Germany, Belgium, and the Netherlands) in the forms of heavy precipitation and flash floods. Even though the Netherlands has a long history of significant investment into water infrastructure and flood defense, it was still severely impacted by the largest flooding event in the southern province of Limburg since 1995. Although no deaths occurred and flood routing measures have appeared to decrease the potential severity of the event, it was noted that public infrastructure related to vulnerable populations was affected by the floods in a way that severely hindered evacuation efforts.

Across the globe, another series of major floods occurred in Australia in 2021-2022 (specifically in New South Wales and Queensland), with similar consequences observed. Residents became isolated after critical infrastructure systems and transportation links were damaged and subsequently failed when severe precipitation fell and caused several creek systems to flood. Roughly 400 mm of precipitation was recorded within 24 hours, causing a mass evacuation of residents and damages to personal property (Queensland Reconstruction Authority, 2022). Queensland was severely affected by flood events 11 years previously during its last once in century flood event.

With future climate change projections indicating more erratic weather patterns and precipitation events globally, governments both national and local should focus more on resiliency to these possible scenarios. Resilience to environmental disturbance events could be a more prominent feature in urban development plans to ensure safety and swift response rates, especially to public facilities associated with vulnerable populations (i.e., hospitals, nursing homes, public schools, etc.). Future resiliency and risk mitigation strategies in urban planning with an emphasis on human vulnerability may help reduce impacts of flood events while decreasing recovery times. According to World Meteorological Organization (WMO) Secretary-General Prof. Petteri Taalas, "There are new levels of awareness and political commitment at the highest levels to tackle the impacts of climate change. Early warning systems and risk-informed action are the most effective ways to adapt to climate change and to reduce the number of casualties and reduce economic losses from extreme events."

The Netherlands and Australia are both highly developed nations that have experienced devastating disaster events in the past. Both countries also invested into large-scale risk assessments following their previous disasters in order to avoid undesirable impacts in the future. One lesson that might be inferred from the events in the Netherlands and Australia is that past risk assessments may have had their scope constrained to larger flood events, and consequently did not identify the potential of more localized, compounding events leading to acutely severe impacts. A general lesson from these events would be to have a renewed focus on preparedness plans and adaptation measures targeted to vulnerable communities in response efforts to minimize disaster impacts and maximize resilience benefits for even larger swathes of the population.

Importance of Disaster Preparation vs. Reaction

Laws governing disasters are often created within the aftermath of major disturbance events and tailored for response and recovery. However, increasing the emphasis of proactive risk management policies through risk reduction could save both lives and resources. Shifting some of the emphasis of disaster management from a response and recovery model to accommodate more risk reduction would require more investment towards pre-disaster infrastructure and warning systems. When focusing on just the economic benefits of pre-disaster preparation, the related decrease in future costs to communities has the potential to be immense. Investing in climate resilient infrastructure provides an extremely high cost benefit ratio of 1:4, and the implementation of early warning systems with only 24 hours' notice can decrease damages associated with storm events by 30% (GCA, 2019).

However, for these systems to be used to effectively mitigate the impacts of disturbance events, it requires preparedness in local planning for response. Preparedness as an approach versus reactionary policies in this context refers to capacity building in both infrastructure and exercising planning sessions with the objective of fostering robust and effective responses and decreasing the damages to life and property (Cigler, 2017). To have a robust and proactive preparatory strategy be successful, investments in capital funds as well as time are necessary to develop expertise long before disaster risk management (DRM) actions are implemented. Unfortunately, proposed investments in preparedness globally have been a difficult policy to pursue due to price and the lack of awareness of the benefits they would provide to local communities. The WMO reported in 2020 that there is a global incapacity for the implementation of early warning systems into early action, even though 40% of its members have these systems in place (WMO, 2020).

One of the Sendai Framework global targets for 2015-2030 is to "prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political, and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience." Increasing resiliency through preparedness requires a communal approach among local governments, private institutions, and their respective national governments based on sharing responsibility. Overall preparedness to disaster events should be a shared responsibility of local and national governments with a focus on both standard practice responses and thoroughly studied contingency coordination roles to react efficiently to anomalies in plans when they occur. Resiliency through preparedness requires networks of resources and pools of skilled labor to coordinate emergency responses at the local level pre-disaster. Further, these groups and individuals must fully understand their role in the larger context during the disaster event.

Local governments often find themselves with less funding and in positions of the most responsibility, while national governments maintain the most resources and are responsible for the aggregate threat of disturbance events (Cigler, 2017). If preparedness is pursued with the goal of allowing local governments/stakeholders more agency, this could help relieve some of the burden from centralized systems by decreasing inefficiencies in later stages. When local governments are engaged to help with the formulation of risk reduction planning, their intimate knowledge of an area's main vulnerabilities can help decrease the likelihood for severe consequences. If pre-disaster community engagement, disaster risk reduction (DRR) infrastructure, and early warning systems are pursued, centralized systems can better logistically focus on the deployment of resources in aid of emergency services response.

How to See, Assess, and Reduce Risk Most Effectively

Climate and water systems are incredibly complex. Both may exhibit prolonged periods of stability with sudden pronounced shifts that can create dramatic results, making risk assessment difficult. The sporadic occurrence of large-scale hazard events leaves most individuals with a lack of firsthand experience when it comes to effectively assessing an area's risk and future risk. Using long-term community outreach programs as an approach to address individual perception of risk is necessary to address cognitive biases that minimize personal risk and reduce damages.

Currently, many countries' national adaptation plans do not assess future trends in vulnerability and exposure risk to population groups, regions, or sectors (Garschagen et al., 2021). With disturbance events projected to increase globally in both frequency and intensity, it is important to increase capacities to assess the risk of environmental hazard impacts on different stakeholders within a region. Terminology describing recurrence intervals of environmental hazard events may be misinterpreted and not adequately convey personal levels of risk exposure to non-experts.

Experts should communicate to targeted groups and stakeholders using appropriate language and a variety of messages that frame risk with the goal of long-term planning and sustained preparedness.

Making relevant disaster risk information open and easily available to citizens helps spread awareness and the ability to assess risk effectively. Using floods as an example, the majority of early warning investment has been focused on technology and equipment. More time and effort could be spent ensuring that these warnings are translated to early action focused on at-risk communities (Perera, 2020). When combined with coordinated outreach programs, a concerted effort should be made to make data regarding disaster risk easily digestible for local stakeholders to discourage misinterpretations and any false sense of security.

Anticipatory thinking towards disaster events is often informed by the ability to interpret just how dynamic and inhomogeneous they can be to an affected area. Facilitating discussions of local preparedness on a community level can decrease perceived risk transference and responsibility of preparation from individual stakeholders onto national agencies

(Paton, 2019). These discussions should state plainly how individual and community level long-term preparedness can complement each other while reducing risks of disaster events overall.

Historical data have shown that local and national governments often will not shift investment actions after disturbance events with small societal impacts, and will respond with robust investments after devastating disturbance events (Aerts et al., 2018). However, these small impact events should be viewed as the risk potential of a system to also exhibit large impact events, and should be responded to with more attention and investment. Even though reviews of every single small catchment or tributary in a nation may not be possible, it should be possible to identify which areas have not yet been fully encompassed in national adaptation plans and protection measures. Simultaneously, local governments are encouraged to review their policies to focus on future trends in risk exposure to the most vulnerable groups and their methods of communication.

Response and Rebuilding as Tools for Adaptation Preparation

Reducing a community's risk of severe impact and overall vulnerability to disasters is paramount as the frequency and intensity of these events increase, whether due to climate change or from the exposure of a growing and urbanizing population expanding into hazard-prone areas. While preparation is essential as part of the necessary shift from reactionary to proactive disaster management, effective responses to disasters can go a long way towards reinforcing the preparatory process.

Priority 4 of the Sendai Framework focuses on "building back better" in the recovery, rehabilitation, and reconstruction phases post-disaster. This period of loss, trauma, and often chaos immediately following a major climatic event is an opportunity to not only help the most vulnerable, but to lay the groundwork for more effective protections and responses against the next disaster. Opportunities to rebuild communities, to fortify defenses, and to plan more proactively abound. For example, following 2012's Hurricane Sandy in the U.S., President Barack Obama called in the expertise of the Netherlands to structure a new approach to the post-disaster reconstruction of New York in an effort to come up with inclusive, cross-cutting, and future-proof projects to reconstruct a city resilient to climate change (NL Platform, 2022).

In its 2018 report Building Back Better, the World Bank proposes three avenues for improving the disaster recovery and reconstruction phase: building back stronger, building back faster, and building back more inclusively (World Bank, 2018). The rationale behind this approach is to reduce the impact of future events while minimizing societal and economic harm of recent disasters. It is also only possible if the appropriate policies, resources, and decision making frameworks are put in place ahead of a disaster — again linking preparedness and recovery.

As will become more apparent throughout this paper, the pace and unpredictability of climate change may necessitate a fourth principle for disaster response and recovery: building back with flexibility in mind. Stronger and more robust infrastructure is often optimized or designed to protect against a specific intensity of water-related disaster impacts (e.g., higher seawalls for larger storm surges). But what happens when disasters behave more erratically or unpredictably? Or when they lead to novel or cascading impacts in an increasingly interconnected world? Barring the ability to predict future events with high confidence, flexibility and adaptive planning will be essential in terms of assessing and designing infrastructure and management options.

Any type of effective recovery and reconstruction will require engagement across a range of actors — not just government entities. The Dutch "Water as Leverage" program provides a positive example of an inclusive approach to addressing climate-related challenges, inclusive of DRM. This public-private-partnership (PPP) brings together financial institutions, NGOs, local businesses, and government representatives (city scale or otherwise) for an interdisciplinary and inclusive process of designing climate resilient adaptation and disaster recovery options.

Risk Transfer Instruments

A recurring challenge of disaster risk preparedness and recovery is the availability of reasonably priced, accessible, and timely financial instruments. The economic costs of an individual disaster such as a typhoon or drought can be staggering, sometimes inflicting damage higher than a country's annual GDP. With high costs for reimbursement and payouts (and the associated reconstruction covered by these funds), insurance and lending costs can become prohibitively expensive. Left to themselves, countries and local governments have relatively few options for disaster risk financing and insurance. A number of initiatives and broader changes in disaster risk financing are beginning to address these challenges. Lines of credit, new partnerships, technological and data advances, and pooled risk instruments present vital opportunities for financing disaster preparedness and recovery efforts.

The World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) joint initiative "Disaster Risk Financing and Insurance (DRFI) Program" is being used to incentivize governments to "become more effective risk managers, rather than borrowers." This is done by establishing prearranged lines of contingent credit to provide emergency liquidity based on the investment and implementation of policy reforms and financial instruments. The program aims to help developing nations better absorb the effects of disaster and climate shocks by acting as a neutral broker bringing together stakeholders to invest in technical advice (GFDRR, 2022).

In the United States, the National Flood Insurance Program (NFIP) determines flood risk and prices flood insurance with the goal of making rates easier to understand and better reflecting flood risk to property. In the event of large floods, the policy covers direct physical losses to structures and belongings. This coverage is used in communities that are then required to adopt and enforce floodplain management regulations and mitigation techniques to increase resiliency for future disaster events (FEMA, 2022). This is coupled with a variety of "premium discounts" that are given for the implementation of mitigation measures. The NFIP is also backed by the US Treasury to address losses that might be above the NFIP's ability to pay.

An emerging rapid financial response tool for national governments known as disaster-insurance risk pools, or multi-country risk pools, or sovereign catastrophe risk pools provides an alternative with attractive cost-saving incentives. It allows countries to access more capital more quickly. Risk pools are especially useful for developing and fragile economies as they "provide pooled expertise for developing risk modeling of extreme weather and pooled finances to access market capital" (Academy of Management, 2022). Since around 2007, these risk pools have been scaling up with support from development banks and donor countries.

These financial tools provide quick access to capital in the immediate aftermath of disasters when it is needed most. Other traditional sources of support such as international development and humanitarian aid can take months to arrive, which can in turn lead to secondary humanitarian disasters as communities struggle to secure basic necessities like food, shelter, and clean water. A more comprehensive analysis of available financial tools for DRR is provided in Chapter 4 of this report.

In the private sector, traditional insurance companies globally are attempting to improve planning to protect portfolios from climate risks even though physical risk exposure in relation to climate change protections remains relatively uncertain. Both private and public institutions dealing with the financial risk associated with climate change are attempting to adapt their methods and tools of risk calculation to better incorporate the high levels of uncertainty that are created from an increase in global temperatures and other hydroclimatic changes. These methods and tools are now beginning to consider not just disaster and climate risk, but also transition risks from moving away from industries previously dominated by petrochemicals and their derivatives.

2

State of Understanding on Climate and DRR

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Understanding Climate Attribution

Whenever an extreme weather or climate-related event occurs, the media and decision makers ask the question to what extent it is influenced by climate change. For a few years now, the scientific community has been able to answer that question for relatively simple extremes: hot and cold extremes, extreme precipitation, and drought. This emerging field of climate science is called extreme event attribution.

Scientific studies going through peer review are usually published a year or longer after an event occurred, once the public has moved on and questions about rebuilding or relocating have been answered without taking scientific evidence on the role of climate change into account. The World Weather Attribution (WWA) initiative, a collaboration between climate scientists at Imperial College London in the UK, KNMI in the Netherlands, IPSL/LSCE in France, Princeton University and NCAR in the US, ETH Zurich in Switzerland, IIT Delhi in India, and climate impact specialists at the Red Cross / Red Crescent Climate Centre (RCCC) around the world, has been founded to change this. The WWA initiative's goal is to provide robust assessments on the role of climate change in the aftermath of the event.

How Does Extreme Event Attribution Work?

Since WWA started in 2014, the group has developed methods to do extreme event attribution quickly but thoroughly. The first step is to decide which events to analyze. For this, an objective trigger criterion has been developed by the RCCC, although less impactful events can also be analyzed if deemed important by an interested party. The expected outcome of the attribution analysis plays no role. Within the analysis, the meteorological characteristics of the event are defined, choosing the metrics that are as salient to the impacts as possible. This is done in collaboration with local experts whenever possible. Long, homogeneous observational time series are analyzed to obtain an estimate of the observed changes (the detection step).

To attribute the change to anthropogenic emissions (or not), the analysis uses as many climate models as possible. The models' performances are evaluated to determine which ones represent the most realistic extreme, all before computing the probability of these kinds of events due to anthropogenic climate change. These estimates are combined with the observed trend in a synthesis that produces a coherent attribution statement. In addition, trends in vulnerability and exposure that contributed to the impact are analyzed.

The Role of Attribution in Decision Making

This relatively new area of science — often simply called event attribution — is rapidly advancing. The advances have come about both because the understanding of the climate and weather mechanisms that produce extreme events is improving, and because rapid progress is being made in the methods that are used for event attribution analysis. Event attribution is being used for a range of disasters, including:

- droughts
- extreme rainfall
- extreme snow and ice storms
- tropical cyclones
- extratropical cyclones
- wildfires
- severe convective storms.

This emerging area of science has also drawn the interest of the public because of the frequently devastating impacts of the events that are studied. This is reflected in the strong media interest in the connection between climate change and extreme events, and it occurs in part because of the potential value of attribution for informing choices about assessing and managing risk and in guiding climate adaptation strategies. For example, in the wake of a devastating event, communities may need to make a decision about whether to rebuild or relocate. Such a decision could hinge on whether the occurrence of an event is expected to become more likely or severe in the future — and if so, by how much.

Has Our Understanding of the Role of Water and Disasters Changed?

Changes to the Larger Water Cycle

Discussions around water-related disasters often tend to focus on the impacts on human lives and assets from isolated events and phenomena such as flooding, droughts, and sea level rise, but not on the combined systemic threat of a disturbed water cycle. Yet there is increasing evidence of the water cycle being disturbed, with attribution mixed between land use changes, climate impacts, and other drivers (e.g., Gordon et al., 2001). The water cycle connects the entire ecosystem; therefore, an understanding of its dynamics and interactions is critical for systems management and ultimately, resilience.

One ongoing global change is an increase in atmospheric water vapor disturbances, with corresponding impacts such as reduced or disappearing rainfall, coupled with increased extreme rainfall. In the atmosphere, not only is the water cycle intensifying due to a hotter climate and the increased water holding capacity of the air, but water vapor flows are also changing direction and intensity due to shifting patterns of land use and subsequent changes to evapotranspiration and air temperature (from, for example, deforestation and urbanization) (Ellison et al., 2017). Atmospheric water vapor flows are often transboundary, and therefore difficult to address (just like terrestrial transboundary waters). Changes originating in one country have direct impacts in others. To further complicate the situation, atmospheric water vapor is not governed by anyone. Taking all parts together (atmospheric as well as terrestrial), human knowledge is only now starting to grasp the large-scale disturbances of the water cycle at a global scale. The following sections will highlight some mechanisms and examples of this emerging challenge.

Terrestrial Dryness: Drivers and Solutions

One emerging insight is the seriousness and consequences of increased terrestrial dryness. Water is leaving the continents at an increasing rate through increased evaporation, straightening of rivers, removal of wetlands, deforestation, changing land use practices, and urbanization, among other reasons. These changes have gradually reduced soil moisture, groundwater, and vegetation.

While the pace of change may be increasing, drying out of the landscape has occurred over a long time — for centuries, if not millennia. For example, Plato (ca. 428 - 347 BCE) already commented on the degradation of the Greek landscape in his work Critias:

> *"In the primitive state of the country, its mountains were high hills covered with soil, and the plains were full of rich earth, and there was abundance of wood in the mountains. Of this last the traces still remain, for although some of the mountains now only afford sustenance to bees. There were many other high trees and abundance of food for cattle. Moreover, the land reaped the benefit of the annual rainfall, not as now losing the water which flows off the bare earth into the sea, but, having an abundant supply in all places, and providing everywhere abundant fountains and rivers. Such was the natural state of the country, which was cultivated, as we may well believe, by lovers of honour, and of a noble nature, and had a soil the best in the world, and abundance of water, and in the heaven above an excellently attempered climate."*

This drying out has potentially disastrous consequences when it comes to sea level rise, extreme precipitation, and floods. Sea level rise is a major threat to coastal communities, increasing the risks from storms and coastal flooding, and could threaten assets worth up to 20% of the global GDP by 2100 (Kirezci et al., 2020). Recent studies of endorheic water loss (water loss through evaporation or seepage into the ground, not through being connected to oceans) have shown that from 2002 to 2020, inland continents lost water mass at the rate of 0.87 mm of sea level equivalent per year, which was greater than the 0.76 and 0.39 mm of sea level equivalent water mass lost per year by the Greenland and Antarctic ice sheets respectively. This water loss equals an additional sea level rise of 4 mm, or approximately 10 percent of the observed sea level rise during the same period (Wang et al., 2018). These significant changes help to illustrate the potential role of sustainable land use management for abating sea level rise.

The increase in continental dryness is also interrupting the so-called "small water cycle," which recirculates moisture on land. While long water cycles draw their moisture primarily from the ocean, smaller water cycles release water into the atmosphere through plant water vapor. A well-known example of this is forests producing their own rainfall. Research published in the 1970s showed that the Amazon rainforest generates around half of its own rainfall (Salati et al., 1979). A forest can also enable the lateral movement of water into continents. Several researchers have shown how forests play an important role in providing "stepping stones" for water into arid areas (Sheil, 2018). This knowledge complements the dominant understanding of forests as only large consumers of water, contributing to reduced base-flows. Such knowledge can have significant relevance for the design of projects aimed at combating desertification.

As an example, in the Sahel, recycling of moisture through evapotranspiration appears to be responsible for more than 90% of the rainfall (Savenije, 1995). Conversely, with increased drying out and a reduction of vegetation due to deforestation, land use changes, or other causes, water available for recycling is reduced.

Scientific and social understanding around these types of systemic impacts on the water cycle is still growing. What does it mean that countries in such extreme drylands are losing their forest cover? For example, Ethiopia was once covered by 30-40% forest up to the late 19th century. Now it is 4.5%. Today, Ethiopia is struck by recurrent droughts that have increased in frequency. With failed rains since 2020, the results are catastrophic, affecting an estimated 6.8 million people who are living in Oromia, SNNP Southern Nations, nationalities and People's Region, Southwest, and Somali regions (OCHA, 2022). It is perhaps mere speculation to link deforestation with the lack of rainfall in this instance. However, the fact is that these types of humanitarian disasters demand a better understanding of the complex linkages between large-scale deforestation and changing patterns and reduction of rainfall. Deforestation is a global challenge, although the good news is that global forest cover is currently increasing (Potapov et al., 2022).

Reforestation is not the only solution. Soil, moisture and water and ecosystem conservation measures on agricultural lands have demonstrated that a lot can be done to address desertification. For example, the Dust Bowl was the name given to the drought-stricken Southern Plains region of the United States, which suffered severe dust storms during a dry period in the 1930s. During this time, temperatures also increased, people and livestock were killed, and crops failed across the entire region. Through several government programs, such as establishing the Soil Conservation

Service, the land use degradation could be halted, temperatures reduced, and the drought gave way to a more life-enabling climate. However, with amplified evaporation and depletion of groundwater aquifers, the risk of another Dust Bowl has increased (Scharping, 2021).

Addressing Urban Heat Islands and Extreme Rainfall Events

Another emerging insight is the role of urban heat islands for extreme precipitation and the moderating role of green areas — especially trees and forests — on the climate. These green spaces have a significant cooling effect on surrounding areas, producing clouds that deflect radiation and reduce the urban heat island effect. Many urban areas are therefore extremely hot from the removal of greenery. In recent years it has become increasingly evident how extreme weather events such as flooding and heatwaves are heavily impacting highly constructed (i.e., urban) areas. Large-scale heat islands have also been shown to affect the spatial changes in precipitation distribution, with a resulting increase in extremes of weather. For example, in the Netherlands, there are studies indicating that increased urban land use has influenced extreme precipitation (Golroudbary et al., 2017).

Climate change is triggering a significant decrease of rainfall in drier areas, with dramatic increases of precipitation in colder regions. At the same time, where there is moist air, more water is available in the atmosphere. With climate change and higher temperatures, evaporation from the ocean will be higher and water vapor will be transported further inland. Powerful storms cause large volumes of moist air to rise rapidly in a constrained region, leading to intense condensation leading to rapid and localized extreme rainfall (Makarieva et al., 2013). Once heavy rainfall hits and floods occur, these volumes of water are difficult to absorb in a drier landscape that has reduced the water capturing elements — resulting in faster runoff to valleys and the reduction of a landscape's ability to retain water and recharge groundwater. In urban zones, pavement (e.g., roads, sidewalks, parking areas) and buildings prevent infiltration and further channel the water, leading to fast runoff of rainwater and driving urban flooding. Investments in green elements that delay and infiltrate the water in catchments, involving all actors and incentivizing investments and policies, are needed at the regional level.

Although the knowledge of the role of ecosystems for disaster risk reduction is significant, greening urban areas is still proving challenging to implement. Existing forecasts of global urban expansion demonstrate that 290,000 km² of natural habitat is likely to be lost between 2000 and 2030, posing a serious threat to biodiversity, moderation of climate and the water cycle, and ultimately sustainable development (Laurance and Engert, 2022). The global reduction of urban greenery and the development of urban heat islands is influencing urban extreme weather and precipitation. However, there is little knowledge on future projections on a global scale.

Water as a Connector

Water is a common connector among different sectors and across borders. The importance of collaborating across these divides is even more significant in times of water-related disasters. Integrated Water Resources Management (IWRM) at a basin level is one useful approach in reducing disaster risks, centering on water's enabling and connective role in enhancing cooperation and minimizing risk. This section will examine management of water as a connector across sectors, as well as across borders.

Managing Water Across Agencies, Sectors

In responses to floods and extreme droughts, which are often historically administered by national Disaster Risk Reduction Agencies, more emphasis is being put into systems thinking as of late. This approach encourages a focus on connections between sectors to address the root causes of vulnerability as a means to prevent extreme events from becoming disasters. Given water's intrinsic relationship with the climate, many such vulnerabilities materialize through the water cycle. Thus, at the research, policy, and strategic level, the sustainable development of water resources is being conducted as an essential input into disaster risk reduction strategies.

In spite of such insights and knowledge, water's current management is often fragmented. This is demonstrated by the degree of implementation of IWRM as part of SDG 6.5.1, which was found to be 54% as of 2020 (UNEP, 2021). As a result, there is a large disconnect in enabling integrated actions and investments that could otherwise reduce the risk of such water-related disasters. When considering the four dimensions of IWRM, the current fragmentation in water management becomes more apparent (the enabling environment, institutions and participation, management instruments, and financial tools). It thus follows that increasing the integration of water resources within and across sectoral approaches to disaster risk reduction (agriculture, energy, fisheries, urban development, etc.) would not just generate significant progress on SDG 6 on clean water and sanitation, but also on SDG 13 on climate action, among others, in the indivisible spirit of the global goals.

The need for integration of water into sectoral approaches can be more keenly appreciated when viewing some of the slow-onset impacts of climate change. In addition to increased extreme hydrometeorological events, the earth's surface has become less able to support crops, livestock, and wildlife due to its overall reduced water holding capacity. This degradation of the earth's surface has a considerable financial impact. In Niger, for example, the costs of degradation caused by land use change amounts to around 11% of its GDP (Moussa et al., 2016). Similarly in Argentina, the total loss of ecosystem services due to land use/cover change, wetlands degradation, and land degrading practices on grazing lands and selected croplands is equivalent to about 16% of its GDP (Bouza et al., 2016). Such slow-onset disasters — indirectly linked to water — arguably contribute to migration, unrest, and social conflict, substantially adding to the human suffering of drought and flood stricken regions. Actions to address slow-onset disasters (i.e., preparation and adaptation) can thus contribute to numerous social co-benefits.

One of the greatest challenges is that resources are needed to combine investments that work to prevent risks linked to diffuse effects from the degradation of the earth's surface. Investments need to be pooled, and stacked benefits need to be valued (both in economic and non-economic terms) across entire landscapes or areas. However, for this to be possible, institutional and sectoral silos must be broken down to allow for long-lasting solutions that do not generate undesired externalities. Thus, only a holistic, all-of-society approach with both horizontal (between agencies on the same governance level) and vertical (between levels of governance) integration could prevent the degradation of soils, water resources, and ecosystems through the combined impact of mitigation, adaptation, sustainable land management, and freshwater use. The very reference to the use of the term "water sector" is contradictory to this objective, since water in this sense is very much a cross-cutting connector, and not a mere sector.

Managing Water Across Borders

While jurisdictional borders are created by humans, naturally, waters have no borders. They cross different municipalities, provinces, and countries. Yet managing transboundary water that crosses different sovereign states in times of water-related disasters can have direct and very meaningful impacts on human lives. A recent example of this is the European floods in 2021. That year, severe floods in riparian countries of the Meuse River exposed operational challenges of transboundary water systems and the need for amplifying climate services and disaster risk governance at different levels and scales.

In practice, managing transboundary water necessitates countries sharing a basin to collaborate in preparing for water-related disasters. A guide developed by UNDRR and UNECE provides a step-wise approach to such joint DRM tactics. This includes:

1. Jointly defining goals and the scope of preparedness, and defining roles of basin organizations
2. Analyzing relevant international and transboundary level agreements, and ensuring relevant clauses are included in agreements
3. Engaging all relevant basin stakeholders and defining their roles and responsibilities
4. Assessing disaster risks through sharing data and basin-wide joint modeling and vulnerability assessments, common information, and early-warning systems
5. Forging agreements of priority measures of transboundary relevance, and developing a basin-wide strategy
6. Implementing measures and sharing costs and benefits
7. Carrying out joint or coordinated monitoring and evaluation.

In addition to the steps outlined above, the HELP has published principles for water and peace in times of water-related disasters. (HELP, 2022)

In managing water-related disasters in transboundary basins, a multi-level governance approach is crucial, recognizing different levels and scales of jurisdictions and the coordination required for effective action. Engagement of all stakeholders at different levels is key to successful management and preparedness. An example of transboundary level flood risk management can be seen with the Danube River, where the basin is shared by 19 countries.

The International Commission for the Protection of the Danube River (ICPDR) was established by riparian countries as a coordinating body. Coordinated by ICPDR, the Danube Flood Risk Management Plan has three parts: a) international basin wide level, b) national and sub-basin levels, c) sub-unit level that is defined as management units within the national territory. The Danube Flood Risk Management Plan offers rich and comprehensive information about flood risk management measures to be taken in the Danube River Basin, and is updated every 6 years with engagement of stakeholders. The challenge of coordinating multiple levels lies in the vertical coordination between and among countries with different histories, conducting different activities, and having their own legislations (UNECE & INBO, 2015).

Water-based Adaptation

Water is at the center of numerous climate change concerns, as made increasingly noticeable given climate change's effects on the water cycle and extreme events in recent decades. Recently, the scientific community has recognised the importance of water in adaptation and climate change mitigation. In March 2022, the Intergovernmental Panel on Climate Change (IPCC) emphasized the importance of developing "water-based adaptation" to boost global efforts to combat climate change. Additionally, most global frameworks and goals, including the Paris Agreement, the 2030 Agenda for Sustainable Development, and the Sendai Framework for Disaster Risk Reduction, also recognise water as the "climate connector" that facilitates greater collaboration and coordination. Hence, water is no longer viewed only as a threat; an increasing emphasis on water resilience is presented as the solution. It is a means by which we can achieve both societal and ecological resilience by incorporating climate adaptation, sustainable development, disaster risk reduction, and recovery.

Resilience Thinking

Since climate change will continue to disrupt the hydrological cycle, water management and decision making must begin to more systematically incorporate resilience thinking. When faced with profound uncertainty, resilience thinking is an approach meant to ensure a system's ability to adapt to and recover from climate impacts, as well as transform when recovery is no longer possible. Resilient water management has two fundamental components: the capability to tolerate anticipated vulnerability (robustness) and the capacity to adapt when expected outcomes deviate (flexibility). This also necessitates developing robust approaches to handle climate consequences with a high probability of occurring, as well as flexible solutions and approaches to addressing concerns with a high degree of uncertainty.

The ability of water systems and communities to dynamically adapt to, respond to, and recover from a variety of climate shocks and stresses can assist society in preparing for the uncertainties associated with climate change. Implementing the concept of water resilience, on the other hand, necessitates collaboration across governance levels, the application of the proper tools for diagnosing the challenges, and an evaluation of the potential sustainable development solutions. Typically, these approaches take into account numerous forms of available infrastructure systems, such as traditional, nature-based, and "green-gray" hybrid approaches. Infrastructure projects typically present an opportunity to address a specific water concern when making development decisions, necessitating an awareness of how to plan and design in the face of uncertainty. Numerous and cascading uncertainties of socioeconomic situations, urbanization, and ecohydrological variables must also be considered by decision makers (Mendoza et al., 2018).

New Paradigms to Assessing Risks

Water managers, engineers, and planners have historically predicted future water supply based on past trends and baselines. Climate uncertainties and other drivers of change also make the planning, regulations, and infrastructure design and operations much more difficult than in the past. Hence, traditional business-as-usual approaches and practices can lead to inaction or even mal-adaptation. The predominant paradigm in water management has been strongly connected with the notion of using the past to accurately anticipate and plan for the future — an idea generally ingrained within "top-down" approaches over the last fifty years. Oftentimes, these approaches do not consider or incorporate the local context and constraints associated with the decision making, while minimizing engagement with important relevant stakeholders.

Conversely, an emerging paradigm of risk-based resilient water management approaches are designed to help decision makers prepare for various climatic futures by implementing measures that can withstand the growing climate and hydrological variability, while calibrating future estimates to the required level of certainty (Timboe et.al., 2020). In recent years, several new resilient water management tools and methodologies have emerged for analyzing and managing climate and non-climatic risks, as well as for addressing more comprehensive policy responses and ensuring long-term community support. These "bottom-up" approaches are intended to integrate into the existing planning, design, and operational decision making processes by heavily integrating stakeholder interaction from the project's inception through success measurement and evaluation, placing a much greater emphasis on the local context such as the local water system, the project's vulnerabilities, the level of analytical uncertainty, and the risk tolerance of the decision makers.

In general, bottom-up approaches necessitate an understanding of the specific decision context associated with uncertainties, the identification of risks and opportunities to develop robust solutions, and the consideration of maintaining the flexibility of these solutions in multiple climate futures. Combining resilience to extreme events and adaptability to dynamic situations can be applied to all facets of water resources management decision making, such as infrastructure design, institutional assessments, policy formulation, and/or the evaluation of tradeoffs. Several bottom-up approaches have become quite prominent and are being applied in dozens of countries while being mainstreamed by major development and finance institutions.

Confronting Climate Uncertainty in Water Resources Planning and Project Determination: The Decision Tree Framework (Ray and Brown, 2015), launched by the World Bank, is a step-by-step approach to decision making that detects the perceived vulnerability of a water resource project, investment, system, or strategy and increases the depth of study. The approach emphasizes the analysis of tradeoffs between the various facets of water resources management in the context of a changing climate and multiple uncertainties. Adaptation Pathways (or Dynamic Adaptive Policy Pathways) (Haasnoot et al., 2013) emphasizes adaptability and risk minimization through a structured and dynamic planning methodology. This strategy permits policies to evolve over a project's lifespan, considering any system changes and creating new vulnerabilities and opportunities to prevent becoming "locked-in" with a single approach. Finally, UNESCO and the International Center for Integrated Water Resources Management (ICIWaRM) published Climate Risk Informed Decision Analysis (CRIDA) (Mendoza et al., 2018), which is a decision support system that includes governance and finance to assist water resources planners in navigating uncertainties in planning, design, and operations with socially acceptable solutions.

3

Policy Processes: National and Global

by Valentin Aich[1], Pan Ei Ei Phyoe[2]
1 Global Water Partnership
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Preparation vs. Reaction

Early Warning Systems and the UN's 5-year Plan

Between 1979 and 2019, a hydroclimatic disaster has occurred on average every day. And on average, it has taken each day the lives of 115 people and caused USD $202 million in losses, according to a 2021 World Meteorological Organization (WMO) report on disaster statistics (WMO, 2021a). The statistics also show that the reported number of disasters is on the rise and has increased fivefold in this 50-year period. At the same time, the number of lives lost has only increased threefold, which can be attributed to better weather forecasts and warnings and proactive disaster management. A flagship report of the Global Commission on Adaptation (GCA) came to a similar conclusion and found that a 24-hour warning for a coming storm or heatwave can reduce the damage by 30% (GCA, 2019). Translated into the benefit of action and cost of inaction, investments in early warning systems can save lives and assets of at least ten times their cost, particularly when investing in developing countries.

Despite these numbers, adequate Early Warning Systems (EWS) are still not in place everywhere. A recent survey amongst all National Meteorological and Hydrological Services (NMHS) around the globe undertaken by WMO (WMO 2021b) has revealed that early warnings for the negative impacts of floods and droughts are still far from being available for all people around the globe. 34% of the NMHSs that answered the survey have no EWS or inadequate versions for floods. For drought, the situation is even worse, with 54% of all countries not having adequate systems. These numbers might even be optimistic since the 92 NMHSs did not respond to the survey (of 193 in total). This means that in many parts of the world, the population is surprised by these hydroclimatic hazards and there is no adequate lead time to prepare and react.

In order to change this situation, the United Nations (UN) has set an ambitious five-year deadline for countries to ensure that their citizens are warned ahead of hydroclimatic hazards. UN Secretary-General António Guterres tasked WMO to lead on this effort and present an action plan to achieve this goal at the 2022 UN climate conference (COP27) in Egypt. WMO estimates that the investment needed in this five-year period to improve the quality of the services and related infrastructures, especially in the Least Developed Countries (LDC) and Small Island Developing States (SIDS), will be around USD $1.5 billion.

The five-year plan on how to scale up the implementation of EWS for hydroclimatic extremes is currently in development by WMO. It will integrate all existing efforts in this field and convene all key agencies, countries, and groups that are working in the field of Hydromet and Risk-Informed Early Warning System capacity development.

People-centric Early Warning Systems

In many developing and developed countries, the number of victims and overall impacts caused by floods and droughts are still very high despite the establishment of EWS. Often warnings fail in the case of a real emergency due to gaps either on the "last mile" of the warning chain or because the recipients are not prepared to react adequately to the warning. This is especially true for the most vulnerable, including refugees, impoverished populations, women, the elderly, and other marginalized groups who are usually forgotten when planning the warning chain.

The Integrated Drought Management Programme & Associated Programme on Flood Management (APFM), operated jointly by WMO and Global Water Partnership (GWP), focuses on overcoming these gaps by engaging communities and other relevant stakeholders already in the design and later in the operation of End-to-End Early Warning and Alert Systems. As a specific example, WMO is implementing a USD $7.92 million regional climate adaptation project titled Volta Flood and Drought Management (VFDM) in partnership with the Volta Basin Authority (VBA) and GWP West Africa to provide the first large-scale transboundary implementation of Integrated Flood and Drought Management strategies through the complete chain of End-to-End Early Warning System for Flood Forecasting (E2E-EWS-FF) and Drought Monitoring & Prediction in the six riparian Volta Basin countries (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali and Togo). The VOLTALARM platform of the VFDM project is a Multi-Hazard Early Warning System (MHEWS) currently under development, operated by the NMHSs. The open-source platform will provide timely warning information to the civil security services and other private and public stakeholders, covering the complete risk reduction value chain — from vulnerability and risk mapping to forecasting, warning dissemination, and decision support. It will be used to connect the available meteorological, hydrological, climatological, social, and structural databases and other validated outputs, such as hydrological modeling systems, decision support, and early warnings from related projects and initiatives at the local, national, and regional level.

Convergence Between Sendai, Paris, and SDGs

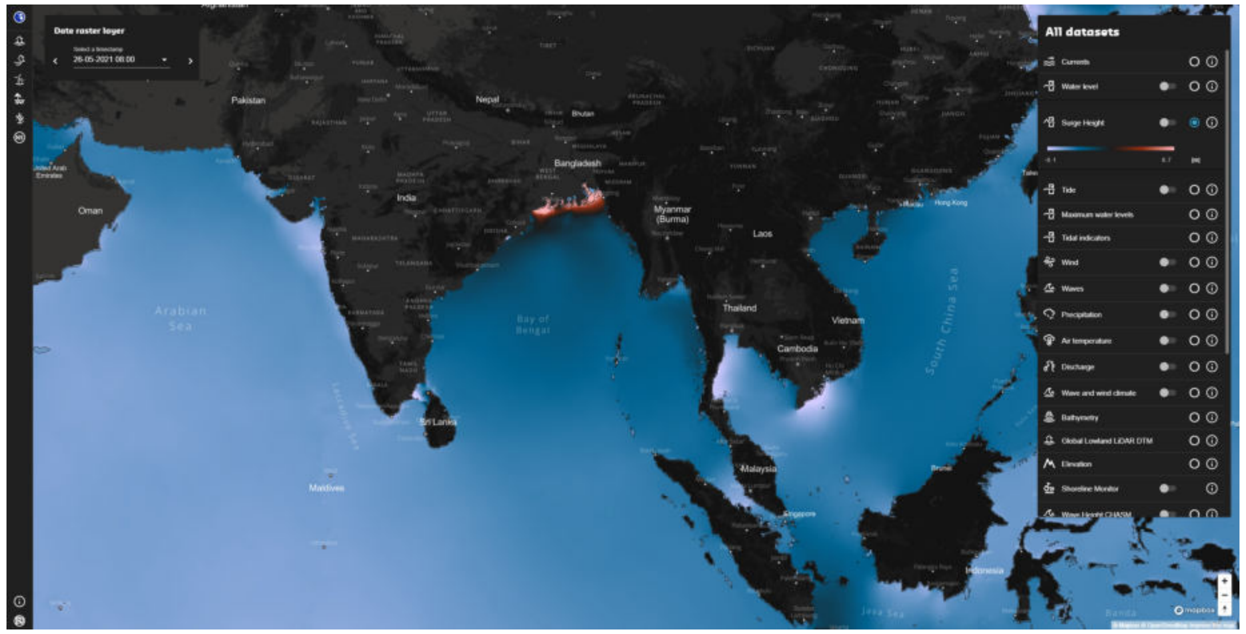
The increasing challenges of managing the risks of climate change and disasters threatens the international community's ability to achieve a wide-ranging swath of global ambitions. The 2015 Sendai Framework for Disaster Risk Reduction, the Paris Agreement on Climate Change Action, and the 2030 Sustainable Development Agenda provide the basis for sustainable and equitable economic, social, and environmental development. These global policy instruments — all established within the last decade — provide a clear mandate for enhanced coherence in countries' climate and disaster risk reduction (DRR) efforts by building resilience to shocks and stressors at the heart of them. They also lay out actionable paths forward through the setting of national goals and targets related to DRR and climate change adaptation (CCA). While this section focuses predominantly on these three policy instruments, there are several others that are also key in shaping and impacting global DRR efforts. Coherence and coordination with the United Nations Convention to Combat Desertification (UNCCD), the Convention on Biological Diversity (CBD), and the Ramsar Convention on Wetlands will be essential for countries, better allowing them to capitalize on limited resources (political and financial) while achieving multiple policy goals.

When it comes to addressing risks such as those from water-related disasters, shifting from a more individualized approach within each policy framework towards a systemic view of risk will go a long way towards more effective action at a national level and beyond (Murray et al., 2017). Interlinkages between the Paris Agreement's adaptation and loss and damage provisions, as well as the Sendai Framework and Sustainable Development Goals (SDGs), should all be taken into consideration and methodically evaluated in order to develop a broad strategy for enhancing resilience (Cody et al., 2021). Targeted actions to promote cross-coordination and cooperation include the provision of organizational support, including funding, technology transfer, and capacity building.

Many countries increasingly recognize the benefits of better coherence across CCA, DRR, and sustainable development activities. They have either developed joint strategies or implemented processes that facilitate coordination across the policy areas. This requires strong commitments and coordination, as numerous ministries and divisions of government are involved in National Adaptation Plan (NAP) processes, Nationally Determined Contributions (NDCs), SDG-achieving strategies, and DRR plans and initiatives.

Countries are making efforts to limit vulnerability and exposure to climate change, as evidenced by initiatives designed to mainstream resilience into national policies. Most DRR requests at the national level center on adaptation measures, such as developing risk and vulnerability maps and enhancing capabilities for health and disaster management.

In practice, many challenges still face countries as they work towards better integration across policy frameworks. Due to the lack of policy coherence and the institutional, technical, and financial capacity restrictions when integrating DRR and CCA policies and plans, many difficulties arise when countries attempt to operationalize their commitments. For example, one of the challenges facing policymakers working on effective coordination is the issue of balancing short-term benefits with long-term planning. The need to minimize risk over the long term and increase resilience can sometimes be in tension with more short-term political horizons. Furthermore, the requirement for medium- to long-term planning for climate action — notably



in managing risk across timescales — overlaps with the need for short-term risk reduction. DRR often emphasizes underlying, short-term risks, while CCA focuses on inherent vulnerabilities (RCRCCC, 2022).

Therefore, NDCs and NAPs are crucial tools for communicating countries' adaptation and mitigation policies as well as demonstrating how DRR planning is connected to climate action. By drafting an NDC, stakeholders are given the chance to bridge gaps and are compelled to acknowledge the importance of current DRR and preparedness efforts in short-, medium-, and long-term CCA planning and financing. Importantly, countries are making use of their NDCs to lessen the risks and effects of disasters even as the number of such events is increasing. According to a recent analysis, 83 of the 190 countries that submitted their initial NDC contained DRR and/or disaster risk management (DRM) (NDC Partnership, 2020; UNDRR, 2021). The inclusion of water in NAPs improves climate resilience and water security, which supports adaptive water management practices and DRR response measures. This integration may improve a country's ability to carry out its commitments to adaptation in its NDC, including the achievement of SDG targets related to water and climate resilience (among others) and implementation of actions targeted in the country's National Communication.

There are examples of DRR and CCA being integrated effectively at the national level to lessen vulnerability through the development, application, and evaluation of multi-hazard risk reduction strategies, policies, and measures. DRR and CCA priorities both place a strong emphasis on systemic risk mapping, planning, and monitoring and the need for a thorough understanding of the vulnerability, risk factors, and social attitudes. Integration across DRR and CCA would be further improved by the addition of guidance on the prioritization and sequencing of appropriate measures within these assessments of the risks associated with climate and disasters (OECD, 2020). According to the OECD country examples assessment, in Ghana the Ministry of Environment, Science, and Technology must approve all budget proposals from different ministries that are related to, or can affect, the environment. In Peru, climate and disaster risks are included in appraisal guidelines for all public investments. In the Philippines, in order to get a budget allocation, climate change adaptation or actions to minimize catastrophe risks must be included in the overall Philippine Development Plan (OECD, 2020).

Water presents a binding thread across sectors, making it a natural point of interaction for CCA and DRR efforts. Water services and water resources experts and agencies should always be engaged in DRR planning and implementation. As countries continue to devise and carry out plans to increase resilience to shocks and stressors — climatic or otherwise — coordination across the major policy frameworks with water as an entrypoint will go a long way towards meeting multiple objectives in an environment of limited resources and mounting global challenges.

4

How Does Finance Support and Enable Effective DRR?

by Aude Farnault[1], Balazs Stadler[1], Xavier Leflaive[1], Harry Smythe[1], & Catherine Gamper[1]
1 OECD

The Economic Case for Investing in Water-Related Disaster Risk Reduction

Water-related disasters entail significant costs to economies and societies, and are expected to rise in the future due to a number of factors including the increasing concentration of assets in hazard prone areas and the impacts of climate change. They represent the majority of disaster losses and damages[1], and their impacts spread through multiple channels. Recorded figures on disaster damage underestimate the actual costs of disasters — particularly social and environmental impacts. A number of analyses have sought to assess the economic benefit of disaster risk reduction (DRR) in terms of avoided damages and losses, but also in terms of the generation of additional social and environmental benefits (such as improved health or improved irrigation practices).

The Costs of Water-related Risks on Economies and Societies

Water-related disasters[2] account for the majority of natural disaster-related losses and damages. In 2017, 92% of such losses and damages recorded on the EM-DAT database were water-related; much of which remained uninsured and those affected were not financially prepared (HELP and OECD, 2019). The World Economic Forum ranked water crises number one in its 2015 assessment of global risks (World Economic Forum, 2015). As highlighted in Figure 1 below, from 1980 to 2021, over 70% of disasters[3] in OECD countries recorded in the EM-DAT database were water-related.

1 There are different definitions of losses and damages. A definition would look at "damage" as being the direct costs and "losses" the opportunity costs. In general, "loss" tends to be unrepairable (or unreplaceable), whereas "damage" can be repaired (or replaced).
2 There are three primary water-related hazards (riverine, coastal floods, droughts, and storms) which may lead to water-related disasters when there are people or economic goods exposed to such hazards and where there is insufficient preparedness or prevention (Asian Development Bank, 2015).
3 EM-DAT distinguishes between two generic categories of disasters: natural and technological. This analysis focuses on the natural disaster category.

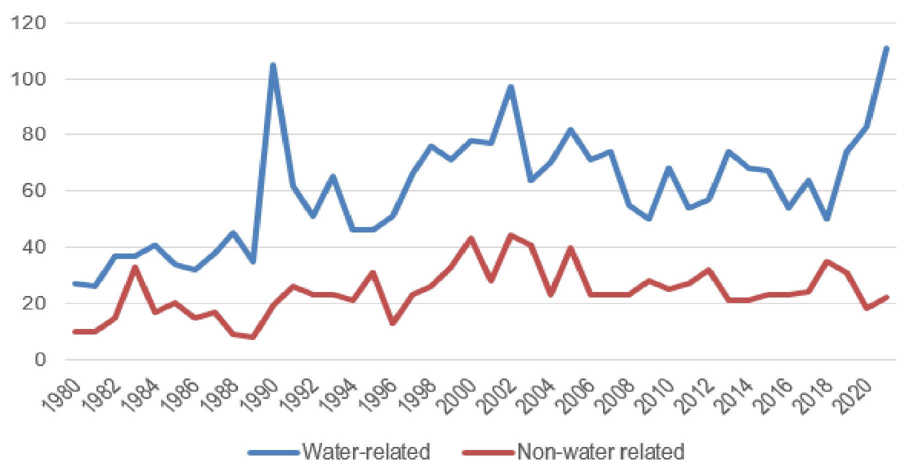


Figure 1: Number of water-related and non-water-related disasters in OECD countries. Source: Authors' calculation based on EM-DAT data. Source: D. Guha-Sapir, R. Below, & Ph. Hoyois - EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be

The economic and social costs resulting from water-related disasters are high and increasing. This is largely driven by the growing concentration of people and economic assets in water-related hazard areas (HELP and OECD, 2019). What is more, climate change exacerbates the frequency and intensity of water-related disasters and droughts (IPCC, 2018) and the degradation of ecosystems increases the vulnerability of populations and physical assets to water-related disasters (HELP and OECD, 2019). There is significant evidence of the cost of water-related risks to economies and societies, today and in the future (OECD, 2021a). Here are some revealing figures:

- Over the past 20 years, floods and droughts alone caused more than 160,000 casualties and caused estimated economic losses of almost USD $700 billion (EM-DAT, 2019). Further, the number of people exposed to floods is expected to grow from the current 1.2 billion to 1.6 billion by 2050 (UN, 2020). Similarly, the value of assets exposed to flood risk will grow to USD $78 trillion by 2040 (Four Twenty Seven, 2020).
- Today, over four billion people live in areas subject to severe freshwater scarcity at least one month every year (Mekonnen and Hoekstra, 2016) and about 1.2 billion people live in extremely water-scarce agricultural areas (FAO, 2020). By 2050, 52% of the world's population is projected to live in water-stressed regions (Kölbel et al., 2018). By 2040, over a third of today's agricultural area will be subject to high water stress, threatening food security in some regions (Four Twenty Seven, 2020).

The impact of water-related disasters can propagate through multiple channels, such as through disruptions to industrial operations or supply chains, impacts on agricultural commodity markets due to water scarcity, or droughts' impacts on production (OECD, 2022c). For instance, analysis from CDP shows that water-related risks can have large impacts on business value, now and increasingly so in the future; the potential financial impact of water-related risks to businesses would be over five times higher than the cost of addressing them (CDP, 2021).

These risks can materialize at multiple scales, from the household to corporate level, to industry and sector scale. They potentially cut across geographical scales, from local to basin and from regional and global levels (OECD, 2021a). For instance, according to S&P Global, water stress would be the main medium-term climate risk for Europe's biggest economies (S&P Global, 2021).

While water-related disasters disrupt socio-economic activities and cause substantial damage. Yet, their full economic impact remains largely unknown, especially the cost of indirect impacts such as those due to business disruptions. The true costs of water-related disasters are underestimated by recorded disaster damage figures (HELP and OECD, 2019). Many disaster loss and damage estimates reflect the replacement value of physical assets that have been recorded as damaged or destroyed. To account for the full impact, estimates would have to include opportunity costs as well as other social and environmental damages that are not usually recorded in monetary terms (impacts of temporary or permanent displacement of people, or social and psychological impacts of an event including on mental health, etc.) (OECD, 2018a). The impact of disasters on human welfare and the distributional impacts can be masked when focusing only on asset losses (Hallegatte et al., 2017).

Finally, it should be noted that the impact of water-related disasters depends on the income level of the affected country (HELP and OECD, 2019). Economic damages and losses tend to be higher in absolute terms in high-income countries, whereas the relative share of damages in proportion to national GDP is higher in low-income countries (UNISDR and EM-DAT, 2018). The social costs (health, fatalities, etc.) tend to be higher in low-income countries.

Multiple Benefits of Investments in Water-related DRR Measures

Water-related DRR should encompass a set of policies aimed at reducing existing risks ("corrective risk reduction measures"), as well as complementary measures that avoid creating new water-related disaster risks ("prospective risk reduction measures") (HELP and OECD, 2019). The corrective risk reduction measures include the structural ("hard") measures (investments in physical infrastructure that aim at reducing the risks for communities and economic assets in areas prone to water-related hazards), the nature-based solutions, non-structural ("soft") measures (including emergency preparedness measures, aiming at reducing damages and losses in the event of a disaster), and investments in infrastructure maintenance (to avoid additional damages and losses). The prospective risk reduction measures include cross-sectoral public and private investments (urban development, infrastructure, and others) and "building back better"[4] measures during the recovery and reconstruction phases (HELP and OECD, 2019).

While the returns on investment of DRR measures are highly context- and hazard-specific, a number of analyses have attempted to evaluate the economic benefit of such measures in terms of avoided damages and losses. The table below provides an overview of the key findings of these studies. For each dollar invested in water-related DRR, the return is estimated to be between USD $4 and $11 in avoided costs, depending on the study (Table 1).

Building resilience to water-related disasters can achieve multiple objectives that are secondary to the main objective of avoiding disaster losses and damages. Among other co-benefits, many risk reduction measures can deliver additional social and environmental benefits (Vorhies and Wilkinson, 2016). For instance, the construction and use of drainage pipes to reduce flood risk can improve irrigation practices. Training farmers in crop diversification and drought resistance can reduce vulnerability to poverty and food insecurity. However, incorporating environmental and socioeconomic co-benefits into traditional economic assessments remains a key challenge (HELP and OECD, 2019). Indeed, environmental and resource costs and benefits are not commonly estimated, as estimating them is methodologically challenging with no consensus on a recommended approach. Different methods of measuring environmental costs and benefits exist, which are more or less effective, costly, and appropriate in different contexts (OECD, 2022b).

Table 1: Overview of studies examining the economic benefits of DRR measures. Values are in U.S. dollars. Source: HELP and OECD, 2019

Key finding	Hazard(s) examined	Source & Context
For every $1 invested in DRR, there is an estimated return of $11 in avoided costs	Hurricane surge, earthquake, hurricane wind, riverine flooding	National Institute of Building Sciences (NIMS, 2018) – Assessment of the benefits of designing buildings to meet 2018 building code specifications, as well as analysis of 23 years of federally funded mitigation grants, United States
On average, every $1 invested in DRR can render benefits of $4 for avoided and reduced losses	Flood, wind, earthquake	(Mechler, 2016) – Review of 52 cost-benefit analysis studies on DRR interventions, Global
For every $1 invested, DRR investments largely pay off, with an average of $5 saved through avoided and reduced losses	Flood	(Mechler et al., 2014) – Review of 27 cost-benefit analysis studies of flood DRR, Global
On average, every $1 invested in DRR can render benefits of $4 for avoided and reduced losses	Flood	(MMC, 2005) – Review of 4000 risk reduction grant programs, covering a range of interventions, United States
Capital investment in risk-reduction measures can achieve a whole life cost-benefit ratio of 1:9 or higher	Flood and coastal erosion	(Environment Agency, 2014) – Assessment of national flood and coastal erosion risk measures, United Kingdom

4 Which depend on how losses affect income and consumption during the recovery and reconstruction phase and who is affected.

5 "Building back better" is the idea that assets that were destroyed during a water-related disaster should not just be built back in the same way in the same location.

Current Under-Investment in DRR and a Clear Reliance on Ex Post Response

Despite the strong economic case for investing in water-related DRR, there is evidence of a general under-investment in ex ante risk reduction and a clear tendency to rely on ex post responses (to a greater or lesser extent depending on country contexts). Existing evidence shows that countries tend to allocate far more funds to disaster response than to DRR. Indeed, the financial case for investing in DRR is not straightforward (long-term benefits, opportunity cost issues, lack of political incentives, etc.). In addition, a significant amount of investments still contribute to increasing exposure and vulnerability to water-related risks.

Lack of Clear Justification for Prioritizing DRR Financing

Despite the strong economic case for investing in DRR, the reasons for prioritizing the financing of DRR are not always clear and well-understood. While the recording of expenditures in national budgeting frameworks for ex ante risk reduction spending versus ex post expenditures is incomplete (OECD, 2018a), evidence points to a tendency of countries towards allocating significantly less funds to disaster reduction than disaster risk response (HELP and OECD, 2019).

Ex ante disaster risk management represents a very small proportion of overall international development assistance. According to OECD statistics, of the USD $196 billion of development aid spent on disasters between 2005 and 2020, around 90% was spent on emergency response, 6% was spent on reconstruction relief and rehabilitation, and only around 4% was spent on disaster prevention and preparedness (Figure 2).

Reasons for the ex post bias in spending and the lack of financing in DRR may vary according to country contexts and may include the following (Kellett and Caravani, 2013; OECD, 2014; HELP and OECD, 2019; Healy and Malhotra, 2009):

- Government and international aid disincentives, as expectations of government compensation and international aid ex post impedes upfront investments, including by subnational governments, households and businesses;
- Low levels of risk awareness: underestimation of disaster risks, as highlighted in Box 1 below, and lack of awareness of risk reduction measures;
- Long-term nature benefits, as investments to build resilience often do not produce visible or immediate gains or benefits;
- Unclear opportunity costs in financing DRR, especially in environments where other priorities — even the provision of the most basic of services — remain a challenge;
- Local level decision making on land use and lack of incentive to integrate risk (enforcement issues regarding risk-informed land use planning, etc.); and
- High political visibility for ex post assistance;
- Disconnect between who pays for DRR actions (i.e., taxpayers) and those who benefit the most from DRR spending (i.e., the most at-risk communities).

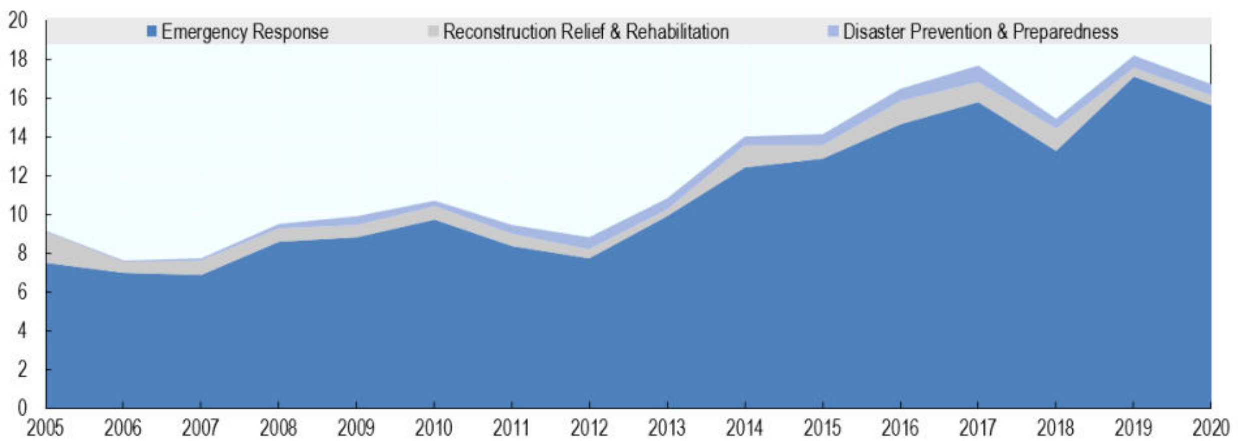


Figure 2: The share of DRR in international aid for disasters, 1991 to 2020 (constant 2010 USD$). Source: Authors' calculation based on OECD statistics

Box 1. Lack of risk awareness leads to overvaluation of properties exposed to floods and lack of incentives to move or take up insurances

Properties exposed to floods or sea-level rise are a well-documented example of how lack of information about climate-related hazards creates market failures. In multiple countries, property prices do not fully reflect the cost of flood and sea-level rise inundation risks. For example, in the United States, the property values in flood plains are overestimated by about 10%. The most relevant explanation seems to be lack of awareness.

Detailed information on hazards, such as maps, became available relatively recently. Consequently, they may not have been internalized by markets. Lack of awareness can be alleviated through personal experience. Once floods materialize and have a direct impact in the area, risks are priced; the property values decrease and demand for insurance increases. Neighboring localities not directly affected by the flood may experience some of this effect. Investigations also indicate a gradual fading of the effect, as people tend to forget or decrease their expectations over time. Therefore, better communication about the risks and possible impacts encourages the property market to price homes appropriately and set the right incentives to move or take up insurance (policies and regulation also play an important role, of course). In France, for example, property sales and rentals are required to disclose risk.

Sources: OECD, 2021b; Sandink, 2015; Storey et al., 2020; Bakkensen and Barrage, 2017; Hino and Burke, 2021; Shao et al., 2017; Pilla, Gharbia, and Lyons, 2019; Storey and Noy, 2017; Gallagher, 2014; OECD, 2016

Investments Still Contributing to Increased Exposure and Vulnerability

Awareness of the potential financial impact of climate-related and environmental risks (including water-related risks) has grown considerably in recent years. Insurance and bank supervisors, as well as credit rating agencies, have started to include water-related risks in their guidance and risk assessments. However, a significant amount of investments still contribute to further exposure and vulnerability to water-related risks (OECD, 2021a).

There could be a "materiality gap" between the substantial economic impact of water-related risks and their (lack of) financial materiality in the global financial system. An event is financially material when its impact would affect the judgment of an investor. The identification of the financial materiality of a risk is a strong driver for actions to mitigate the potential financial impact of the risk (OECD, 2021a).

Several factors may explain why the impact of water-related risks in the financial sector appear to be modest at present, despite the above noted importance of water-related risks for economies and societies. Firstly, current approaches to risk modeling and risk assessment do not fully capture all types of risks, and even when such risks are considered in risk assessments, they are often not fully priced. Secondly, mentions of environmental risks in current prudential regulations for the financial sector are sparse. The example of emerging supervisory guidance in the Eurozone banking system shows that the uptake by banks of environmental risks in their risk assessment practices is slow and limited (ECB, 2021). Thirdly, the financial sector can make use of risk hedging or transfer tools, such as Credit Default Swaps or catastrophe bonds, which may reduce the perception of the financial materiality of the risks in the financial system (OECD, 2021a).

Mitigation action can include reducing the risk, for instance by cutting finance flows to certain sectors or regions. It can include transferring the risk to a third party, for instance via insurance. It can also include setting aside financial resources to cover for future potential estimated losses. In any case, the identification of financial material risks triggers, or should trigger, financial action in the face of the risk (OECD, 2021a).

If and when some water-related risks are considered financially material in the financial system, this could in turn affect the allocation of financial flows, encouraging more money going into investments that reduce the physical or economic exposure and vulnerability to water-related risks, and less money supporting investments that increase exposure and vulnerability to such risks (OECD, 2021a).

Options to Mobilize Additional Sources of Finance for Water-Related DRR

A number of options can be considered to mobilize additional sources of finance to contribute to DRR, including improving systematic reporting and disclosure of physical climate-related risks by asset owners and operators, and making investments in water security more attractive to investors (for instance, using policy instruments to capture the value of investments in risk reduction, identifying and measuring co-benefits, etc.). Governments have an important steering function to align incentives in favor of DRR.

Central Role of Governments in Strengthening Financial Management of Water-related Risks

The role of governments is crucial to ensure that investment flows contribute to reduce rather than increase disaster risk (Watson et al., 2015). To promote investment in water-related DRR, governments should address the market and policy failures that result in an over-reliance on disaster response and recovery (an all too common practice in spite of the strong economic case for investment in prevention). Setting the right policy and regulatory regimes to create a strong national DRR framework is important to incentivize risk reduction, in both public and private investments (ISDR, 2011). A key step is to align incentives of the central government and the rest of society, including households, businesses, the financial sector, and sub-national governments (OECD, 2022a). Central governments have an important role to play through designing disaster risk financing mechanisms (HELP and OECD, 2019). For instance:

- Compensation for damages and losses incurred by households and businesses: while governments recognize their responsibility to guarantee the health and safety of citizens in the event of a disaster, policies aimed at providing financial disaster assistance to citizens and businesses can undermine DRR efforts in the long term. Rewarding efforts of those stakeholders that invest in self-protection before disasters occur is a good incentive mechanism (HELP and OECD, 2019). For example, a premium-based insurance (such as flood insurance in Romania) would help to align incentives in this direction, despite the political difficulties of implementing a mandatory public insurance with premiums (Hanger et al., 2018).
- Cross-governmental cost and benefit sharing mechanisms: most countries have implemented cost sharing mechanisms between central and subnational governments as well as between central government funding agencies and other sectoral agencies affected by water-related disasters. Good practices in which central governments (such as Australia) have provided higher levels of contributions to sub-national governments for rewarding forward-looking investments in risk reduction (e.g., building back better measures[6]) are emerging (HELP and OECD, 2019).

In addition, the development of proactive financial management instruments can help mitigate the fiscal impacts of water-related disasters on government's budgets. These instruments provide financial protection, as they can transfer risks to those better able to absorb them, or reduce costs by redistributing risks across time (OECD, 2015a). Specifically:

- Risk transfer[7] mechanisms include risk transfer from the government (e.g., catastrophe bonds) and risk transfer from households (e.g., insurance), which have different impacts on fiscal resources. For example, in Mexico, the natural disaster fund (FONDEN) has secured reinsurance coverage of approximately USD $400 million to provide a source of funding for the reconstruction of public assets and public housing after a disaster has occurred (Kellett and Caravani, 2013; HELP and OECD, 2019). The African Risk Capacity (detailed in Box 2 below), a regional risk pool established by the African Union, helpS African governments to plan, prepare, and respond to disaster risk, including water-related ones. However, as losses and damages tend to increase, risk transfer mechanisms may reach their limits, as this trend could lead to a situation where some risks are no longer transferable or insurable.
- Risk retention instruments, such as disaster management funds, can allocate or redirect budgets to help provide quick access to funds in the face of frequent and low-intensity weather events. Credit from international development banks for unforeseen circumstances is more appropriate for medium-frequency, medium-intensity events. The volume of funds needed to better cope with more intense and less frequent hazards usually exceeds the immediately available funds from government budgets (OECD, 2021a). The adoption of a financing strategy by the government to make sure sufficient funds are available in the event of a disaster is essential. Such financing can be put in place within the government budget or obtained externally through pre-arranged credit facilities (HELP and OECD, 2019).

Benefits of Improvements in Transparency and Disclosure of Water-related Risks

Improvement of systematic reporting and disclosure of physical climate-related risks by asset owners and operators may help redirect investments that increase vulnerability to water-related risks. Better disclosure (and thus acknowledgement/understanding) of these risks can incentivize private sector risk management and mitigation, and inform investors' decisions (OECD, 2018b). According to a study by Banque de France, investors subject to climate reporting have reduced their investments in fossil fuels by 40% (CDP and Planet Tracker, 2022). This is suggestive evidence of the impact that disclosure can have on redirecting investments. Until now, financial institutions have often not disclosed the water risk management and mitigation measures they were taking across their portfolios. Given the scale of the challenges ahead

Box 2. The African Risk Capacity

The African Risk Capacity (ARC) is a regional risk pool established by the African Union. It helps African governments improve their capacities to plan, prepare, and respond to extreme weather and climate events through collaboration. To that end, it helps countries harness state-of-the-art technology, as well as gain access to innovative finance mechanisms. While droughts are common across Africa, the ARC assumes they will not likely occur in the same year in all parts of the continent.

In return for an annual premium payment, participating countries can access pay-outs if a predetermined triggering event occurs. The risk transfer parameters selected by each country determine the pay-out threshold.

The ARC on average covers USD $30 million per country per season for drought events that occur with a frequency of one in five years or more (though the exact amount varies widely). The ARC makes payouts to the national treasury within two to four weeks of the end of the rainfall season. Subsequently, the treasury can use the pay-out to support affected households using a pre-approved contingency plan. The ARC expands climate risk insurance coverage through ARC Replica, an insurance product for the World Food Programme and other humanitarian partners. It aims to improve the effectiveness of emergency humanitarian response in vulnerable African countries prone to climate risks.

To be eligible for the ARC, participating governments must develop a contingency plan. This outlines how they will use pay-outs quickly and effectively. It also describes how they will reach those most impacted by the extreme weather event in an efficient and timely manner to protect livelihoods. Whereas the funds ideally should be implemented within 120 days of an ARC pay-out, funded activities should be completed within six months.

Providers of development cooperation, along with participating African Union members, can contribute to the ARC through annual premiums. For example, as part of its COVID-19 Emergency Programme, Germany provided premium payments in 2020 for the ARC to support up to 20 million people in the 2020-21 agricultural season. The United States, the United Kingdom, and Switzerland have also supported ARC member states and replica partners with premium financing.

Sources: OECD, 2021b; ARC, 2021; WFP, 2018; BMZ, 2021

6 However, it should be noted that this notion has limits. For instance, in California, insurance regulations required rebuilding to the same standard, which meant rebuilding in increasingly risky areas (this regulation has recently changed but it remains complicated).

7 Risk transfer involves the shifting of risks to others who, in exchange for a premium, provide compensation when a disaster occurs, ensuring that any financing gap that might emerge is partially or fully bridged.

and the potential to trigger substantive outcomes, regulators are taking steps to address this and to adapt existing climate disclosure policies to incorporate water (CDP and Planet Tracker, 2022). The recommendations of the Task Force on Climate-Related Financial Disclosures (TCFD)), promoting and increasing consistency in climate-related financial disclosures across countries and companies, have given greater impetus to such efforts. Building on efforts of the TCFD, the U.S. Securities and Exchange Commission (SEC) in 2022 proposed a new rule to standardize climate-related information in statements and reports submitted to the commission. Designed to help investors assess climate risk, companies would also be encouraged to disclose information on climate-related opportunities and any plans related to achieving internal climate-related targets in a more standardized fashion (Dewey, 2022).

Central banks can potentially play a key role. The Network of Central Banks and Supervisors for Greening the Financial System is one of the main pioneers of assessing physical climate risks on financial risks (NGFS, 2019). Yet only around one-tenth of the world's central banks have mandates to consider environmental sustainability (Dikau and Volz, 2021). Finance supervisors have started to provide guidance on the integration of water-related risks in global financial system risk assessments (e.g., ECB and NYDFS). However, the financial system appears to be slow in its uptake of the assessment of those risks, and many institutions continue to rely to a large extent on historical rather than forward looking data, despite evidence that these risks are present and mounting (OECD, 2021a). There may be a role for the water community to engage with finance supervisors to bridge the data and methodological gaps that may prevent a quick uptake of risk assessments by the financial system. However, the trigger for such collaboration must come from a willingness of the financial system to change its practices. For instance, financial regulators together with the water community could focus their efforts on measurement of water-related operational risks for banks (OECD, 2021a). Measuring the potential impact of water-related risks on banks' premises, and including the risk assessment in the prudential reporting would be a relatively quick win. It could contribute to enhancing the water-related risks culture within the banks, opening the way for a larger update of risk assessment tools beyond the operational risk.

Water-related transparency from companies is also fundamental to limit the risk of water-related stranded assets. Indeed, water-related issues have already stranded assets across several sectors including coal, electric utilities, metals and mining, and oil and gas. Shifts in water-related regulation and community oppositions, for instance, are having significant implications for firms. Lack of information on how the firm accounts for water issues in its growth strategies and whether it invests in solutions means uncertainty for investors on the company's fundamentals and the risks it faces (CDP and Planet Tracker, 2022). Financial institutions could lobby their portfolio companies directly, and can also become signatories to the different initiatives to support improved water disclosures.

Options to Enhance the Attractiveness of Water-related DRR Investments

A number of options can be considered to attract more investment to DRR, and particularly private investment. The rise of climate finance could be an opportunity for attracting more funds for DRR finance. While adaptation to climate change requires broader actions than DRR, there are also overlaps. These include integrating climate-related risk into development planning and generating risk management frameworks as well as a range of other measures (Kellett et al., 2014). As finance for climate change adaptation is being directed to build resilience to extreme climate events, the DRR component of climate adaptation finance is likely to increase.

In addition, the following set of options can be explored to make water-related DRR investments more attractive to investors (HELP and OECD, 2019; OECD, 2018b; OECD, 2018c; OECD, 2019):

- Improving the calculation of investment benefits, including social and environmental co-benefits not traditionally factored in currently. Indeed, identifying and measuring additional co-benefits can enhance the attractiveness of DRR investments;
- Making sure that public procurement processes are conducive to reducing risks. There are examples of Public Private Partnership contracts taking into account the management of climate-related risks. For instance, in Colombia, increased insurance coverage is required in recent road concessions, in order to reduce potential government liabilities if risks materialize (OECD, 2018b).
- Opting for a flexible approach to investment planning through investment "pathways", i.e., sequenced packages of investments (OECD, 2018c). Investments that avoid lock-in to a given trajectory and costly path dependency provide more flexibility to adjust to changing conditions (e.g., external conditions, policy objectives, etc.). One example is the Delta Programme in the Netherlands which combines a long-term perspective, an iterative decision making cycle, and a dedicated fund to guide and implement investments for flood protection (OECD, 2018c). The "water as leverage" approach (Ovink et al., 2021) also advocates for an integrated approach to water investment planning, with the idea of breaking through the fragmentation in the project development process and moving away from a narrow focus on projects;
- Using policy instruments to capture the value of investments in risk reduction and provide a revenue stream for investments (e.g., via value capture mechanisms).

Box 3. Land value capture – A suite of tools to finance water-related investments, including DRR – The cases of Morocco and Czech Republic

According to the "beneficiary pays" principle, expressed in the Vancouver Declaration during Habitat I, the beneficiaries of public investments that valorize their land should partly cover such costs or return their benefit to the public. The means by which beneficiaries can pay back include: taxes, such as land taxes and betterment charges; development charges or permit fees; pricing and compensation policies; adequate assessment of land values; and leasing publicly owned land.

Experience in water-related projects, including in DRR projects, is limited so far. Casablanca, Morocco paved the way. Casablanca is characterized by rapid urbanization; its population is expected to grow from 3.5 million to 5 million inhabitants by 2030. Extending the water network, securing access to the resource, and protecting it against frequent floods are serious concerns for the local authority, which needs to finance these projects. The city defined a new investment program in 2007, including investments to prevent losses from water-related disasters. Revenues from user tariffs cover operational and maintenance costs and the renewal of existing assets (accounting for 70% of total costs over the last decade). A dedicated account (fonds de travaux) covers the remaining costs (essentially land acquisition, network extension, and social connections). Financed mainly by contributions from property developers, it has financed a growing share of total investment, from 7% in 2004 to 54% in 2014.

In Czech Republic, local governments may charge fees in areas developed by small individual investors — typically areas with family houses where each house is built by a different individual. When such private development requires water or sewerage utilities and local governments provide them, developers may have to pay local governments a fee if their plots increase in value due to the connection to the water or sewerage system. This fee does not apply to other types of infrastructure. Local governments set it in generally binding decrees. It cannot exceed the difference in value between land with and without the possibility of connection to the water or sewerage system. The fee is based on the specific plot surface dedicated to the water or sewerage system connection, not the total gross floor area developed. Therefore, it does not take into account the increased water or sewerage system capacity that development may require. This same fee could be applied for other infrastructure provided by the government designed for flood risk protection, for instance.

Sources: UN, 1976; OECD, 2019; OECD, 2015b; OECD and Lincoln Institute of Land Policy, 2022

5

DRR in the Context of COVID-19

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What Are the Dynamics of Simultaneous Crises and What Can We Learn?

For the past several years, "resilience" in the context of water has generally referred to climate resilience – how we respond to shifting, novel, and evolving shocks and stressors. COVID-19 has reinvigorated the conversation around what resilience really means, exposing economies, supply chains, and institutions to new stressors and highlighting the deep uncertainties about future conditions that face societies, businesses, and individuals. Governments and decision makers more broadly are in need of integrative guidance that helps address compounding threats and multi-risk drivers associated with simultaneous crises. Water can serve as a medium of coherence between these systems challenges.

The Intersection of Health and Climate Disasters

According to the International Disaster Database EM-DAT collected by the Center for research on the Epidemiology of Disasters (CRED), floods and storms have occurred the most frequently over the past 30 years (1990-2020) (Mavrouli et al., 2022). Simultaneously, climate-related shocks have continued to be felt increasingly worldwide since the COVID-19 pandemic began in early 2020. Specifically, many water-related events coincided with COVID-19, such as the Asia-Pacific cyclones in 2020 and the July 2021 floods that affected several Central European countries. Heavy rain in Sudan caused the biggest flood in 30 years, affecting approximately 900,000 people (Donoghoe et al., 2022). The Pacific Islands, including Vanuatu, Fiji, and the Solomon Islands, endured Cyclone Harold (Samuwai, 2020), while the Philippines was hit by Typhoon Goni, the second-strongest tropical cyclone on record at landfall (Masters, 2020).

As climate change intensifies, social and economic crises such as the COVID-19 pandemic will intersect with and compound the effects of climate system hazards (e.g., multi-year droughts). The International Federation of Red Cross and the Red Cross Red Crescent Climate Centre reported on the intersecting impact of climate-related extreme weather events and COVID-19 from the beginning of the COVID-19 pandemic until August 2021, finding that 139.2 million people were affected and at least 17,242 people were killed across at least 433 distinct events (Walton et al., 2021). These numbers are certainly an underestimate, and the examples are numerous. African countries including Uganda, South Sudan, and Somalia have already borne witness to this intersection of challenges, simultaneously battling the combined impacts of COVID-19, locusts, and floods (Muhumuza, 2021). In Afghanistan, the combined threat of climate change and COVID-19 intensified existing social and political conflicts, creating even more threatening conditions (Walton et al., 2021).

Moving Towards a More Holistic Disaster Response Approach

Challenges in the Current DRM Response Model

Due to the immediate focus on minimizing COVID-19 infections in the current pandemic landscape, competition and complications between DRR emergency responses and COVID-19 healthcare interventions have exacerbated negative effects in many countries and cities across the globe. COVID-19 also exposed the current shortcomings of DRR and DRM strategies, wherein (generally speaking) disaster management systems could not sufficiently respond to the different types of disasters that multiplied globally, failing to adequately respond to impacts unfolding on multiple timescales and magnitudes.

Since the COVID-19 pandemic regularly intersects with other disasters, countries must adopt multi-sectoral approaches to manage the economic and social effects of the virus that are more cognizant of the resulting pronounced implications on other immediate disaster responses. This is not always easy due to jurisdictional or logistical constraints — or both. A common challenge emerging is the difficulty of coordinating disaster and health responses across national entities and humanitarian and civil society organizations with their own set of priorities, jurisdictions, and constraints. More practically, while adopting COVID-19 risk reduction principles, physical challenges included the logistical constraints of delivering food and water to disaster-stricken populations.

Lessons Learned for Improving Disaster Responses

The Sendai Framework emphasizes the need to increase government coordination to include all risks, including biological hazards. Existing DRR and DRM strategies can provide actual means to respond successfully to epidemics and even global pandemics like COVID-19 (UNDRR, 2020). Although most nations recognize the most common epidemics such as cholera, malaria, measles, and Ebola as hazards, no country has objectives or strategies to reduce the associated risks or strengthen health resilience. The majority of national DRR strategies lack a cross-sectoral approach; however, several national DRR strategies stress the necessity of cooperating with the health sector and identify corresponding entities, such as the Ministry of Health, as part of DRR implementation and coordination mechanisms. Even when governments include health-related activities in their DRR strategies, they are typically not comprehensive, focusing instead on raising awareness or protecting essential infrastructure (UNDRR, 2020).

As the COVID-19 pandemic continues to afflict communities around the world, it is important that planning and responses take into account the implications and complexities of the ongoing climate extremes. The compound risks posed by the pandemic and the escalating climate disasters necessitate coordinated efforts to develop improved insight into drivers of risk and a deeper understanding of the complexities of managing them, such as evacuations during lockdowns.

Given that few climate adaptation measures include aspects of pandemic preparedness or have contingency plans for major or frequent disasters, the current attempts to adapt to climate change have not been sufficient (Ford et al., 2022). Connecting the research, policy, and practices within public health, disaster preparedness, emergency management, humanitarian response, and development planning sectors must take a more integrated approach across sectors and geographic scales. This will require involvement of government actors (from national to city level) as well as non-state actors and the healthcare sector. Such improved disaster management systems should have the flexibility to respond to different types of disasters, with local, state, and national governance levels sufficiently equipped to manage and mitigate their effects (Donoghoe et al., 2022).

Effective responses during a natural disaster require both early preparation and the capacity for local action. Local capacity is always faster and better attuned to local needs. COVID-19 travel restrictions have underlined the importance of investing in local crisis management and local response capacity more than ever before (Walton et al., 2021).

We have witnessed the world investing in unprecedented amounts of international finance to help economies recover from the massive economic damage caused by the global pandemic. It is of the utmost importance that we simultaneously consider how these investments can lead to communities that are more resilient to multiple, often interacting, hazards. Changes in risk management systems to take a more integrated and cross-sectoral approach will go a long way towards minimizing future risks and capitalizing on the lessons learned from the COVID-19 crisis as we move further into an era of escalating health and climate crises.

Lessons from the Netherlands' COVID-19 Response: Focusing on the Most Vulnerable Populations

The Netherlands has taken a more balanced approach to the COVID-19 pandemic when compared to many countries. With major focuses on both containment and mitigation, the government implemented a range of measures to contain the spread of the virus, including initial border closures, social distancing, and contact tracing. The government also implemented a range of measures to mitigate the economic and social impacts of the pandemic, including financial support for businesses and individuals.

The Netherlands has taken several steps to improve its flood risk response considering lessons learned from the pandemic. One example is the introduction of a new national flood risk management plan, which includes measures such as improved early warning

systems, increased investment in flood protection infrastructure, and improved coordination between different government agencies. Additionally, in 2021 the Netherlands implemented a new system of regional flood risk management plans for the Rhine, Meuse, Ems, and Scheldt regions, each tailored to the particular needs of the specific region. These plans include measures such as improved communication between local authorities and citizens, increased public awareness of flood risks, and improved coordination between different government agencies. Finally, the Netherlands has also increased its investment in research and development related to flood risk management, with a focus on developing innovative solutions to reduce the impact of floods.

The Netherlands was swift at addressing the financial and social effects of the pandemic on vulnerable populations. For example, in March 2020 the government passed the Coronavirus Act, which included measures to protect vulnerable groups such as those with disabilities, the elderly, and people with low incomes. The Act provided for an emergency fund of €1.2 billion to support vulnerable people and those affected by the pandemic. This fund was used to provide financial assistance to those who had lost their jobs or had their hours reduced due to the pandemic. In addition, the government passed a bill in April 2020 that provided for an additional €2 billion in emergency funding for social services, followed by another €1 billion in May and another €1 billion in June. All the funds were designed to provide additional support for vulnerable groups through the provision of services such as food banks, shelters, and mental health services. Although to many this was seen as too little to effectively address the situation, comparatively this lesson of early focus on socially vulnerable groups can be also applied in the flood context as well.

Large, reactive relief bills cannot serve as a long-term solution to addressing the financial needs of disaster preparedness and response. Since before the pandemic, governments and international organizations have been working to develop other innovative financing mechanisms that can help vulnerable populations access the resources they need to prepare for and respond to disasters. Some examples include:

1. In 2019, the World Bank launched the Global Index Insurance Facility (GIIF), which provides access to insurance products tailored to the needs of vulnerable populations in developing countries.
2. In 2020, the African Risk Capacity (ARC) launched a parametric insurance product that provides financial protection to vulnerable populations in Africa in the event of a natural disaster.
3. In 2020, the International Finance Corporation (IFC) launched a microinsurance program in India that provides access to insurance products for low-income households.

Future research into the outcomes of these innovative financial products may lead to even more efficient use of funds targeting vulnerable populations before, during, and after natural disasters and other crises.

The Netherlands also implemented emergency changes to its water and disaster management policies in response to the COVID-19 pandemic to better focus on more pertinent disaster risk needs. One example is the Dutch government's decision to temporarily suspend the implementation of the European Union's Water Framework Directive (WFD). The WFD is a comprehensive piece of legislation that sets out a framework for protecting and improving water quality across Europe. The suspension of the WFD was necessary due to the disruption caused by the pandemic, and it allowed the Dutch government to focus on more immediate needs.

Notably, the Dutch government has also implemented changes to its disaster management policies in response to the pandemic. For example, the government has increased its focus on digital communication and remote monitoring of disasters, as well as increasing its investment in emergency response teams. These changes have allowed the Dutch government to better respond to disasters in a timely manner, while also reducing the risk of further spread of COVID-19. However, recent studies have shown that this could be done in an even more targeted manner by amplifying messages sent directly from researchers involved in the fields of the relevant disaster.

One truly innovative technique was pioneered by a small number of countries including the Dutch government that intersected both the realm water and sanitation and disaster management: tracking the Coronavirus through wastewater treatment plants (WWTPs). Tracking of SARS-CoV-2 in sewage was first implemented in the Netherlands soon after the first evidence of fecal shedding of SARS-CoV-2 was reported. The Dutch sewage surveillance network started in February 2020 by monitoring seven WWTPs (6 cities and 1 airport) and gradually expanded until reaching all WWTPs in the country (352 locations) by September 2020. Following the Dutch example, many countries started similar sewage surveillance programs in 2020 (e.g., Australia, Belgium, Canada, Finland, France, Italy, United Kingdom, USA, Spain, and Sweden). At the time of writing, 70 countries have implemented SARS-CoV-2 sewage surveillance programs at different scales and coverages (COVID-19 WBEC, 2023).

Lessons from Japan's COVID-19 Response: Using Effective Disaster Risk Response Messaging

Japan alternatively took a more relaxed approach to the COVID-19 pandemic, relying on citizens to take personal responsibility for their own health and safety. In some regards Japan was already prepared for the effects of a pandemic with their recent experiences with the SARS virus and wide acceptance of masks in society. The government implemented a range of measures to contain the spread of the virus, including travel restrictions and contact tracing; however, the government did not implement a nationwide lockdown or other strict measures. Instead, the government has encouraged citizens to practice social distancing and wear masks in public and relied on a cultural peer pressure system.

The response to the COVID-19 pandemic has also highlighted the importance of effective disaster risk response messaging. Japan has been praised for its effective messaging during the pandemic. The Japanese government used clear and consistent messaging that relied on "societal norms" to inform the public about the risks of the virus and the measures that needed to be taken in order to contain it.

Lessons from Israel's COVID-19 Response: Putting Existing Resources to New Use

The response to the COVID-19 pandemic has also highlighted the importance of utilizing existing resources in responding to disasters. Israel, for example, has been praised for its effective use of its military in responding to the pandemic. The Israeli military was used to enforce social distancing measures, provide medical assistance, and distribute food and supplies to those in need.

Israel relied heavily on their Directorate of Military Intelligence (DMI), positioned as a centralized authority while simultaneously allowing them to play a multifaceted role in the pandemic. Its technological unit created information management software for testing labs. The same unit also conducted epidemiological analysis to identify hotspots of infection. The DMI established the National Information and Knowledge Center for the Fight Against COVID-19 to analyze the spread of the virus and provide data analysis and recommendations to governmental organizations. Additionally, secret units such as Sayeret Matkal were called upon to deliver samples to testing locations, while a group called Unit 81 was responsible for designing sophisticated technology for remote control operations, personal protection gear, and designated ambulances. The DMI was able to provide a wide range of services to support the crisis response.

Several countries used an approach where multiple different agencies oversaw logistical supplies and care, resulting in overly complex and convoluted mixes of responsibilities. The Israeli approach illustrated that it can be quite effective for specific agencies to play a more central role in the delivery of the necessary supplies for disaster preparation and response. Governments could offer the resources of their armed forces and their medical personnel to provide rapid disaster relief services, similar to the emergency response it provided in addressing disastrous levels of COVID-19 infection and death in worst-hit areas during the first phase of the pandemic. If this style of disaster response is implemented in flood risk scenarios, then logistics supply chains can be more quickly deployed while minimizing redundancies.

6

Capacity Development for Adaptive Management

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This chapter is adapted from the Water Policy article "Facing global transitions in water management: Advances in knowledge and capacity development and towards adaptive approaches" by G.J. Alaerts and J.M. Kaspersma (2023).

Governments, water administrations, and actors in civil society should prioritize analysis with a long-term horizon (e.g., for climate adaptation), and develop capacity to do so (e.g., capacity for adaptive management approaches, long-term planning, and capacity to apply instruments for implementation). While long-term programmatic strategies are advocated, the distinct supportive knowledge and capacity development activities should stay realistic and manageable in scope.

A Key Moment for Capacity Building and Policy Innovation

This chapter argues that new systemic challenges are arising in the next three decades that will emphasize the need for more effective policy implementation for adaptive water management. This argument is based on the advances made in the past three decades in practicing knowledge and capacity development (KCD). This forward-looking review thus sits at the mid-point of a period spanning about six decades bounded by the first identification in 1991 of weak institutional capacity as one main reason for the partial failure of the 1981–1990 UN Drinking Water Supply and Sanitation Decade (IDWSSD) (Alaerts et al., 1991; O'Rourke, 1992) and by about the year 2050 that according to many water and climate forecasts risks becoming a tipping point — a milestone by which time better resilience should be achieved. In economies with a robust education system, strong governance, and high levels of communication and transparency, new knowledge can dissipate relatively fast across institutions and society and be applied through decisions in commercial transactions, regulations, and procedures decided at national and local government levels. Citizens and their representatives participate in these processes. In developing economies, on the other hand, new knowledge travels more slowly through a nation. Policy innovation and reform that imply redistribution of power and delegated decision making can only be implemented stage-wise, as the prospective new actors need time to acquire the capacity to understand their new role, agree to it, and start acting accordingly. Policy reform thus rests on simultaneity of political decision and capacity. For capacity to be acquired, political will must exist. And to inform sound political decision-making, capacity is a prerequisite. The effective impact of a policy is predicated on implementation capacity.

Transitions in the Water System

Water sits at the nexus of several natural and social systems that require water to thrive (health, food production, ecosystems, etc.) and, in turn, decide on policies that impact heavily on water. Demographic and economic growth are the main stressors on water. Water over-abstraction and land use changes, including urbanization, increasingly determine local water excess or shortfall as well as overall quality. Most rivers and lakes are already heavily over-used. In many places the abstraction rate from aquifers exceeds recharge; concern is growing across the globe — from the Ogallala aquifer in the mid-west US, to south-western Europe, to India's Rajasthan or China's north-eastern Hebei-Shandong region — that many local stocks will run dry in the next 2–3 decades unless drastic measures are taken to return to sustainable abstraction rates (Famiglietti, 2014; Turner et al., 2019; Gleeson et al., 2020). Over-pumping in urbanized areas, expanding irrigation, and land reclamation trends are now causing land subsidence by 10–30 cm per year over vast areas in Indonesia, the Beijing-Shandong Basin, Mexico City, Central Valley (US), the Ganges and Indus Plains, and the Tehran Plain just to name a few. Much of this subsidence started only in the 1970–1980s. Herrera-García et al. (2021) estimate that from 2010 to 2040 this will expose a population of 480–660 million people and 12–16% of global GDP to intensified flooding. This starkly illustrates how compartmentalized water exploitation and poor land management are exhausting water resources while at the same time dramatically increasing flood risk. In the mid-term, the main drivers for aridification and increased flooding are conversions in land use that channel rain run-off faster to the river, such as by removal of forest canopies and marshland, and urban "hard surface" such as roofs, roads, and parking lots. At the continental scale, vegetative cover evaporates moisture into the atmosphere that in turn feeds precipitation elsewhere. For example, South America's Río de la Plata Basin depends on evaporation from the Amazon forest for 70% of its water resources. Thus, intensive conversion of forest to urban and agricultural land will have a major negative impact on water availability (Van der Ent et al., 2010).

Water, ecosystems, and biodiversity exist in critical mutual dependence. On an estimated 23% of the global terrestrial area, current biomass productivity is estimated to have been depressed by land and water use changes and other interventions, compared to the undisturbed situation; this is affecting 36% of all cropland, pasture, and forestry systems and 15% of natural areas. Biodiversity and ecosystems are by themselves very productive in a narrow economic sense (fish, timber, and produce) but the combination of landscape and vegetation (or "green infrastructure") in turn ensures a healthy regenerative hydrologic system. OECD (2017, 2019) estimates the current global productive value of ecosystems and biodiversity at about USD $140 trillion, or 1.5 times the global GDP, yet these systems are being degraded at an increasing rate. Biodiversity loss was estimated at 34% by 2010 and is projected to continue with about 10% of additional loss up to 2050, a juncture that may turn critical with respect to reversibility in land and soil degradation, further jeopardizing water security (Van der Esch et al., 2017; WWF, 2020). Studies have assessed the overall implications of combined water (over-)use and land use change. Drought appears as the deadliest physical hazard with at present an estimated 3.6 billion people living in areas that are water-scarce for at least one month per year, set to increase to 4.8–5.7 billion by 2050 (i.e., 55–65% of the world population) with over 40% of the world population living in water-scarce river basins under severe water stress, up from about 16% in 2010 (OECD, 2012; Sadoff et al., 2015; WWAP, 2018). Thus, the world started transitioning from a place that is predominantly wet to one that is predominantly arid. Driven by this increasingly unsustainable dynamic, the World Bank (2016) forecasts a likely decline in several countries' GDP of up to 6% by 2050 caused by water-induced losses in agriculture, health, income, and property, with some regions in the world facing sustained negative growth.

Climate change is projected to significantly increase the population facing water scarcity and/or major river floods in the 21st century. The timeframes for the scenario forecasts extend to 2050, 2100, and beyond (IPCC, 2021, 2022). Schewe et al. (2014) calculate that for each degree of global warming, an additional 7% of the global population will be exposed to a decrease in renewable water resources of at least 20%, and on average 4% of the global land area will see a decrease in renewable groundwater resources of more than 30% for each degree of global warming, with 1% of the global land area seeing a decrease of more than 70% (Portmann, 2013). Thus, by the mid-century most regions will be deeply affected by such changes.

The above facts highlight that policy design is transitioning from a paradigm determined primarily by the extrapolation of historical data sets, to one driven by simulated scenario forecasts with a focus on the situation by about 2050. The year 2050 may represent a tipping point, with the water sector looking fundamentally different in the second half of the century than in the first. Finally, where the conventional paradigm assumed that all demand — by households, agriculture, industry, etc. — could be satisfied and that any negative impacts of water appropriation could be mitigated through add-on measures, the new paradigm accepts that the water system has inherent deep constraints and seeks increased efficiency of water use, protection of land and ecological systems, reduction of the "water footprint" of economic activity, and more reliance on a circular economy including efficient water allocation. Capable and well-informed institutions will be essential to all policy planning and implementation.

Transitions in Sector Management: The Case of The Netherlands

er management is also undergoing transformations at the institutional level. In the corporate sector, complexity and uncertainty are being recognized as new systemic features (McGrath, 2011). For the water sector, such transitions are reflected notably in legal and regulatory frameworks, policy documents, and social analyses, which converge in the operational tasks, priorities, and goals as perceived by the leadership of water utilities and agencies. These transformations are not well analyzed yet. However, the authors conducted an exploratory survey and literature review for the situation of the regional (drinking water) utilities and the regional wastewater and flood management agencies (Water Agencies) of the Netherlands spanning the period 1970–2030. Though confined in scope and methodology, the outcomes are considered meaningful and reflect trends in higher-income economies as this country is considered to be performing well on governance and overall capability (OECD, 2014).

Leadership is faced notably by expanding sectoral and water-relevant general regulation including, since the early 2000s, a growing body of EU Directives that together raise requirements (e.g., in drinking and surface water quality, and in financial performance and tariff caps) while narrowing the room for maneuvering in decision making. Stricter regulations on land use, spatial management, and nature protection restrict options for sustained service delivery; many regulations prove simple add-ons rather than streamlined instruments reconciling opposing objectives and tradeoffs. Illustratively, some utilities tend to prefer groundwater for supply augmentation over surface water because the former is less tightly regulated.

Over the past two decades, political and public scrutiny and interference have significantly increased by local governments seeking rents as well as local communities and vocal citizens expressing demands via informal (social media) and formal (political) channels. Water Agencies in 2010 were close to being abolished as they were considered not cost-effective in the then-prevailing market liberalization context. From the 1970s onward, water management has been recognized as knowledge-intensive — relying on novel technologies and a specialized workforce. The sector has had to compete for qualified staff in a structurally tight labor market. Utilities and agencies now increasingly must align with an expanding set of municipal and regional policies such as on saving of water and other resources, decarbonization, and the circular economy. This in turn drives much closer collaboration and integration with other sectors and closer relationships with local and national government administrations and industry. Whereas 50 years ago it was challenging to raise scarce capital for ambitious sectoral expansion investments, this constraint subsided in the 1990s (though less so for the agencies) but is now again a management pre-occupation as large physical assets such as sewers, pipelines, and plants need to be replaced and measures against droughts need to be put in place while tariffs are capped. Finally, the planning horizons have gradually extended to several decades, in line with the growing capacity to forecast sectoral developments and the drive to manage assets and optimize investments. However, this generates significant uncertainty inherent to the forecasting models and the novel nature of many management measures.

Countries in development and in economic transition, on the other hand, arguably are facing a double challenge: complexity (and need for know-how) is growing and changes are rapid. The growth rate of complexity can be illustrated by observing that during the typical career of a water professional, most countries are experiencing rapid growth in demography and prosperity. Simultaneously, their water resources and ecosystems are being exploited to, and now often beyond, their sustainability boundaries. A professional in such a country, educated in the 1980s using textbooks published in the 1970s has a career spanning the period 1990–2030. They must manage the growing pressures on water in that period resulting from a demographic growth of 40–100%, the transition from a rural to an urban landscape, a 10-fold increase in tap connections, and households and industry turning 3–5 times as wealthy, each consuming 2–10 times more water. The fact that these countries often are heterogenous, comprising richer/urban and poorer/rural parts, adds to the complexity. In addition, they are facing the challenge of simultaneously addressing traditional water challenges (e.g., expanding service to all households) and the new ones of changing climate adaptation, rapid urban expansion, etc. They tend to rather rely on infrastructural approaches to manage supply but

have also to start investing in the application of IWRM, institutional development and KCD. At the same time, the need for infrastructure remains large such as, in Africa, for water storage capacity.

6.4 - Moving Forward

The transitions in the physical and institutional realms possess three salient characteristics: complexity, uncertainty, and rapid change. Complexity refers to challenges that are associated with initial ignorance, deep uncertainty, and potential contentiousness. Complex challenges cannot be mastered with straightforward measures (which distinguishes complex from complicated challenges), and they involve many different actors spanning various sectors and jurisdictions. These types of challenges are at least partly in continuous change, meaning that by the time part of the ignorance is unc overed, the circumstances have changed again. Complex challenges are transaction intensive and necessitate an experiential discovery pathway of which the ultimate desired outcome is not guaranteed (Glouberman & Zimmerman, 2004; Snyder, 2013; Andrews et al., 2017). Together, this suggests that two main program lines are unfolding ahead. First, many challenges will project into an uncertain future and need an adaptive, iterative learning approach to uncover realistic pathways towards resolution. Second, the transition from static, bureaucratic approaches to "organic" and dynamic ones able to manage the changes will increasingly necessitate institutional change and policy reform. The water sector needs to explore and equip itself with approaches and instruments to strengthen the knowledge base and institutional capacities required for addressing these transitions while complementing the traditional agendas that remain important.

The Next Challenge: Knowledge and Capacity Development to Support Adaptive Policy Implementation

Adaptive Management Formats

Whereas typical policies are normative, suggesting full knowledge of what needs to be achieved, several authors have proposed policies that are better able to deal with complexity, uncertainty, and rapid change to design and agree on new appropriate policies and implement them effectively. In uncertain situations, experts do not know or the parties to a decision cannot agree upon: (i) the external context of the system, (ii) how the system works and its boundaries, and/or (iii) the outcomes of interest from the system and/or their relative importance. Deep uncertainty also arises from actions taken over time in response to unpredictably evolving situations (Haasnoot et al., 2013). Large-scale investment programs, whether infrastructural (roads, energy, water) or social (education, health, etc.) typically span several decades. The design of the investments in the latter part depends on fundamental early choices (path dependency) at a time when information is constrained most. The gap between available and needed knowledge will be smaller in countries with an extensive knowledge infrastructure and strong societal trust in knowledge and governance; adaptive management (AM) operates better in environments where cultural, financial, and political space exists for "learning" and mistakes. Developing countries, thus, may be at a disadvantage compared to richer economies.

Robust Decision-Making (RDM) (Lempert et al., 2006; Bryant & Lempert, 2010) was proposed as a multiple scenario evaluation framework for making decisions (in rich economies) on large infrastructural programs with a large number of highly imperfect forecasts of the future. Rather than relying on improved point forecasts or probabilistic predictions, RDM describes many plausible futures relying heavily on stakeholder involvement, then helps analysts and decision makers identify near-term actions that are robust across a wide range of futures — that is, actions that promise to do a reasonable job of achieving the decision-makers' goals compared to the alternative options, no matter what future comes to pass. Pahl-Wostl (2007) and Pahl-Wostl et al. (2007) propose AM to continually adjust water management decisions for IWRM where positions of multiple stakeholders and longer-term consequences of decisions are uncertain. Kwakkel et al. (2016), Haasnoot et al. (2018), and Haasnoot & Warren (2019), also working mostly in rich economies on water investments to adapt to climate change, devised Dynamic Adaptive Policy Pathways (DAPPs) that continually adjust early adaptation management to environments that are complex, cannot be fully understood up-front, keep evolving, and are sensitive to path-dependency. Andrews et al. (2017) propose for developing economies a Problem-Driven Iterative Adaptive Process (PDIA) to prepare effective longer-term development policies (irrespective of the sector) of which the outcomes are uncertain. These AM approaches are long-term iterative processes in which at the onset long-term goals are kept generic and vague but the goals of the imminent iteration well-specified, based on the best current insights, and making all assumptions explicit. By systematic monitoring and evaluation of progress and failure, and by assessing the assumptions after each step against expected outcomes, uncertainty is reduced stepwise. Thus, the policy is gradually being implemented using best available knowledge, and information is steadily accumulated to prepare future decisions.

AM is a collection of approaches that help implement programs or change a system by purposefully learning about the system. Surprisingly, only in the PDIA literature is the need for KCD mentioned explicitly; arguably, as the other AM approaches seem concerned with contexts in richer countries, they may assume knowledge and education systems are already in place and sufficiently effective.

Conclusions

Knowledge and capacity have become more broadly accepted since the 1990s in water management and sector development as being pivotal for defining goals and priorities and implementing the activities to achieve these. They have been demonstrated to cause impact and economic return. Yet, their application still tends to be often simplified to either general education or "training."

Admittedly, comprehension of the full scope of KCD is challenging as it necessitates operational understanding of disciplines at the following three levels: (i) how the physical world is under threat and what action needs to be taken; (ii) how the institutional arrangements — policies, organizations, financial flows, etc. — need to be enhanced to achieve what is required under (i); and (iii) how educational, pedagogical, and knowledge-management approaches can be applied to achieve the enhancement and change under (ii). Also in other sectors, knowledge and capacity are being placed at the core of development. Management sciences were first to discover the value of knowledge management, and many successful corporations started to roll out these approaches in the 1990s. In several countries, the sectoral knowledge base and innovation became the subject of dedicated policies. Furthermore, international development theories have highlighted the deficiency of countries in their implementation capacity to convert policy goals into effective action. Finally, in developed economies, notably the health and environmental regulation communities have started developing an "implementation science" to enhance their capacity to disseminate and embed new know-how faster.

KCD is a sticky, slow process — meaning that it requires long-time engagement of many years or decades and adequate budgets. The water sector is facing growing, urgent challenges in the next three decades: the outstanding challenge of achieving the SDGs and the relatively new challenges of adapting to climate change and building more resilient water and land systems. To address these, three agendas can be discerned.

First, current KCD activities and practices need to be scaled up and designed better based on a deeper understanding of effective approaches and instruments, notably applying longer-term programmatic frames and better embedding them in operational work. Second, more structured KCD must be adopted with medium- to long-term perspectives aiming to support change and reform processes at policy and organizational levels in order to address the poor implementation of well-intentioned policies for want of institutional capacity. This challenge pertains to developing and rich countries alike. It calls for the discovery of what constitutes effective implementation through an iterative adaptive process and an implementation science. Third, as pressures on the water and land systems across the globe are rising rapidly, effective policies must increasingly become proactive, shaped by modeled forecasts; organizations and institutions will need to become enabled to change and adapt to future scenarios that are more complex, uncertain, and evolving rapidly. Enhancing knowledge and (institutional) capacity for designing and implementing policies, and establishing "learning organizations" — and, by extension, learning societies — are intensive and time-consuming processes, following iterative adaptive pathways for which sustained political commitments and budgets are preconditions. Therefore, we recommend the following. Foremost, as change and reform programs require long-term and sustained political support, peer-learning among leaders (such as senior managers in the public and private sectors, and politicians) needs to be structured and facilitated, perhaps under the auspices of a new UN High-Level Panel of Government Leaders or multi-sectoral stakeholder groups such as the Water and Climate Coalition. Governments, water administrations, and actors in civil society should prioritize analysis with a long-term horizon (e.g., for climate adaptation), develop capacity to set goals and achieve these, and apply learning approaches and instruments for implementation. However, while long-term programmatic strategies are advocated, the distinct supportive KCD activities should stay realistic and manageable in scope. Third, more dedicated research, knowledge sharing, and advocacy is required, involving practitioners and theoreticians from different disciplines and operating within a global impact monitoring framework; such a framework may develop from the existing framework for SDG 6, but needs to be broader in scope and much more effective in shaping policy. To complete the investments and institutional changes in transitions takes 20–30 years; to be ready by 2050 they should be initiated now.

7 Conclusions and Recommendations

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The main purpose of this flagship report was to give an overview of what we have achieved in the last decade on water-related disasters and what we have learned from past events. The ways in which most countries and communities currently address water-related disasters are not adequately preparing them for the increasing frequency, severity, and uncertainty of these hazards as climate change accelerates in the decades to come. For unprecedented events, but also slow-onset processes, we cannot build on historical trends, as those do not provide guidance on what we experience nowadays and in the future. We need to deal with compound and consecutive events that are increasingly difficult to predict.

In this document we have discussed aspects that need to be considered in preparing for and recovering from disasters that we cannot fully grasp yet — a process which will need continuous further development. The HELP is positioned as a source of authority and guidance on these topics; recommending a number of broader shifts around the preparation, communication, and financing for water-related disasters can not only save lives, but can better position economies to avoid major shocks, while simultaneously advancing countries' goals and commitments around climate adaptation and sustainable development.

The recommendations below can serve as a starting point as the HELP guides countries towards actionable steps to improving their approach to water-related disasters.

1 **Shift from a reactive to proactive approach.**
- According to OECD statistics, of the USD $196 billion of development aid spent on disasters between 2005 and 2020, around 90% was spent on emergency response and only around 4% was spent on disaster prevention and preparedness, with the remainder going towards reconstruction relief and rehabilitation.
- Countries need to set priorities and invest in disaster resilient infrastructure, warning systems, and capacity development.
- When planning climate mitigation activities (e.g., biofuel production, pumped hydropower), consider their water-related impacts to avoid potentially worsening drought or flood risks.

2 **Use disaster response and rebuilding as tools for adaptation preparation.**
- In disaster response, opportunities to more proactively boost adaptation efforts abound.
- Build back with flexibility in mind, not just more robust and optimized for specific intensities of projected impacts.
- When building back for more resilience, integrate horizontally and vertically; establish policy structures that engage all sectors that have been affected and on all relevant administrative levels.

3 **Promote new approaches to assessing and communicating risks — hydroclimatic and financial.**
- A whole set of emerging approaches to assess and address physical climate risks that includes considerations of future uncertainty should be used in disaster risk management planning and design of solutions. They can be used to analyze local risks and are context specific.
- When assessing financial risks, costs, and benefits, support alternative and emerging approaches that factor in a wider range of variables and co-benefits. These emerging approaches include improving systematic reporting and disclosure of physical climate-related risks by asset owners and operators, and making investments in water security more attractive to investors (for instance, using policy instruments to capture the value of investments in risk reduction, identifying and measuring co-benefits, etc.). Governments have an important steering function to align incentives in favor of DRR.
- Misrepresentation of costs and benefits can mean a significant amount of investments still contribute to further exposure and vulnerability to water-related risks.

4 **Prioritize inclusivity in DRM planning, and engage with the most vulnerable communities.**
In line with the HELP Guiding Principles for Incorporating Environmental Justice into Flood Risk Management, we emphasize for disaster risk management that data and information gathering will help us to understand where vulnerable populations are located. Active engagement with disadvantaged communities helps us to better understand their vulnerabilities and impacts. Further, alternative (more equitable) benefit indicators need to be considered when prioritizing and evaluating adaptation measures as we make, implement, and review decisions to reduce, control, accept, or redistribute disaster risks.

- Provide targeted support to the poorest and most vulnerable population groups to lessen the disproportionateIn disaster response, opportunities to more proactively boost adaptation efforts abound.
- Build back with flexibility in mind, not just more robust and optimized for specific intensities of projected impacts.
- When building back for more resilience, integrate horizontally and vertically; establish policy structures that engage all sectors that have been affected and on all relevant administrative levels.ly adverse impacts of disasters and avoid traps to systematically overlook this large portion of the population. Enact policies that encourage and direct funding toward disaster risk management projects that benefit disadvantaged communities.
- Engage proactively with local governments in preparatory efforts. While national strategies are still essential, some decentralization of responsibilities can reduce inefficiencies while capitalizing on local knowledge of the main vulnerabilities and consequences.
- Encourage community engagement and information sharing. Use outreach programs and open communication to promote appropriate understanding of risks and responsibilities.
- Central governments can provide higher levels of contributions to sub-national governments to reward forward-looking investments in risk reduction.

5 **Explore new instruments for risk transfer, pooled finance, and risk retention.**
Water-related disasters entail significant costs to economies and societies, and are expected to rise in the future due to Provide targeted support to the poorest and most vulnerable population groups to lessen the disproportionateIn disaster response, opportunities to more proactively boost adaptation efforts abound.

- Build back with flexibility in mind, not just more robust and optimized for specific intensities of projected impacts.
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- Engage proactively with local governments in preparatory efforts. While national strategies are still essential, some decentralization of responsibilities can reduce inefficiencies while capitalizing on local knowledge of the main vulnerabilities and consequences.
- Encourage community engagement and information sharing. Use outreach programs and open communication to promote appropriate understanding of risks and responsibilities.
- Central governments can provide higher levels of contributions to sub-national governments to reward forward-looking investments in risk reduction.

A number of factors including the increasing concentration of assets in hazard-prone areas and the impacts of climate change. They represent the majority of disaster losses and damages[1], and their impacts spread through multiple channels.

- Communities need reasonably priced, accessible, and timely financial instruments as well as incentives and assistance not to locate in high-risk areas.
- New initiatives and options include: lines of credit, risk transfer mechanisms like catastrophe bonds, insurance to transfer risk from households to the government, and pooled risk instruments.
- Encourage a flexible approach to investment planning through investment "pathways" (i.e., sequenced packages of investments).

6 **Make efforts to align national disaster risk reduction, climate adaptation, and sustainable development activities.**
Many countries increasingly recognize the benefits of better coherence across climate change adaptation, disaster risk reduction, and sustainable development activities. They have either developed joint strategies or implemented processes that facilitate coordination across the policy areas. This requires strong commitments and coordination.

- Develop joint strategies across main national policy frameworks: Sendai Framework, Paris Agreement, and the SDGs.
- Use climate commitments like NDCs and NAPs to create a mandate for disaster risk reduction activities and multi-hazard risk reduction strategies.

Concluding, water should serve as a connector across systems and sectors and should be at the heart of climate change adaptation. Countries will need to utilize horizontal (between agencies on the same governance level) and vertical (between levels of governance) integration and involve water expertise and agencies in all steps of disaster risk reduction and climate change adaptation planning and implementation.

8 There are different definitions of losses and damages. A definition would look at "damage" as being the direct costs and "losses" the opportunity costs. In general, "loss" tends to be unrepairable (or unreplaceable), whereas "damage" can be repaired (or replaced).

References

Introduction

Academy of Management. (2022). How Nations are Collaborating on Disaster Insurance. Research Brief. PreventionWeb. Retrieved from: https://www.preventionweb.net/news/how-nations-are-collaborating-disaster-insurance

Aerts, J. C., Botzen, W. J., Clarke, K. C., Cutter, S. L., Hall, J. W., Merz, B., ... & Kunreuther, H. (2018). Integrating human behaviour dynamics into flood disaster risk assessment. Nature Climate Change, 8(3), 193-199.

ADB. (2023). ADB approves flood assistance package Pakistan. Retrieved from: https://www.adb.org/news/adb-approves-flood-assistance-package-pakistan

Cigler, B. A. (2017). US floods: The necessity of mitigation. State and Local Government Review, 49(2), 127-139.

Doyle, E. E., McClure, J., Potter, S. H., Becker, J. S., Johnston, D. M., Lindell, M. K., ... & Coomer, M. A. (2018). Motivations to prepare after the 2013 Cook Strait Earthquake, NZ. International journal of disaster risk reduction, 31, 637-649.

FEMA. (2022). Flood Insurance. Retrieved from: https://www.fema.gov/flood-insurance

Garschagen, M., Doshi, D., Moure, M., James, H., & Shekhar, H. (2021). The consideration of future risk trends in national adaptation planning: Conceptual gaps and empirical lessons. Climate Risk Management, 34, 100357.

GFDRR. (2022). Disaster Risk Financing and Insurance Program: Strengthening Financial Resilience to Disasters. Retrieved from: https://www.gfdrr.org/sites/default/files/publication/thematic-note-diaster-risk-financing-and-insurance-program.pdf

Global Commission on Adaptation. (2019). Adapt now: a global call for leadership on climate resilience. World Resources Institute: Washington, DC.

Markanday, A., & Galarraga, I. (2021). The cognitive and experiential effects of flood risk framings and experience, and their influence on adaptation investment behaviour. Climate Risk Management, 34, 100359.

Ministry of Planning Development & Special Initiatives (2022). Pakistan Floods 2022: Post Disaster Needs Assessment

NL Platform. (2022). Water as Leverage: What an integrated approach to resilient cities can do. Retrieved from: https://www.nlplatform.com/articles/water-leverage-what-integrated-approach-resilient-cities-can-do

Paton, D. (2019). Disaster risk reduction: Psychological perspectives on preparedness. Australian journal of psychology, 71(4), 327-341.

Perera, D., Agnihotri, J., Seidou, O., & Djalante, R. (2020). Identifying societal challenges in flood early warning systems. International Journal of Disaster Risk Reduction, 51, 101794.

Pesme, J., Cook, S., & Skalon, T. (2021). Resilient finance: Closing the protection gap against disaster risk. World Bank Blogs. Retrieved from: https://blogs.worldbank.org/psd/resilient-finance-closing-protection-gap-against-disaster-risk

Queensland Reconstruction Authority. (2022). 2021-22 Southern Queensland Floods State Recovery and Resilience Plan 2022-24. State of Queensland: City East.

World Bank. (2018). Building Back Better: Achieving resilience through stronger, faster, and more inclusive post-disaster reconstruction. World Bank: Washington, DC.

WMO. (2020). 2020 State of Climate Services: Risk Information and Early Warning Systems. WMO: Geneva.

Chapter 2

Bouza, M. E., Aranda-Rickert, A.,, Brizuela, M. M., Wilson, M.G., Sasal, M. C., Sione, S. M. J., Beghetto, S., Gabioud, E. A., ... & Nkonya, E. (2016). Economics of Land Degradation in Argentina. In: Nkonya, E., Mirzabaev, A., von Braun, J. (eds) Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Springer: Cham.

Ellison, D., Morris, C. E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., ... & Sullivan, C. A. (2017). Trees, forests and water: Cool insights for a hot world. Global environmental change, 43, 51-61.

Golroudbary, V. R., Zeng, Y., Mannaerts, C. M., & Su, Z. B. (2017). Detecting the effect of urban land use on extreme precipitation in the Netherlands. Weather and Climate Extremes, 17, 36-46.

Gordon, L., Jönsson, B. F., Johannesen, Å., Steffen, W., Falkenmark, M., & Folke, C. (2003). Large scale redistribution of global water vapour flows by deforestation and irrigation.

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global environmental change, 23(2), 485-498.

HELP. (2022). The Principles to foster peace before, during, and after water-related disasters. High-level Experts and Leaders Panel on Water and Disasters (HELP). Retrieved from: https://www.wateranddisaster.org/cms310261/wp-content/uploads/2022/08/The-Principles-to-Foster-Peace-before-during-and-after-Water-related-Disasters_final.pdf

Kirezci, E., Young, I. R., Ranasinghe, R., Muis, S., Nicholls, R. J., Lincke, D., & Hinkel, J. (2020). Projections of global-scale extreme sea levels and resulting episodic coastal flooding over the 21st Century. Scientific reports, 10(1), 1-12.

Laurance, W. F., & Engert, J. (2022). Sprawling cities are rapidly encroaching on Earth's biodiversity. Proceedings of the National Academy of Sciences, 119(16), e2202244119.

Makarieva, A. M., & Gorshkov, V. G. (2010). The biotic pump: Condensation, atmospheric dynamics and climate. International Journal of Water, 5(4), 365-385.

Makarieva, A. M., Gorshkov, V. G., & Li, B. L. (2013). Revisiting forest impact on atmospheric water vapor transport and precipitation. Theoretical and Applied Climatology, 111(1), 79-96.

Mendoza, G., Jeuken, A., Matthews, J., Stakhiv, E., Kucharski, J., Gilroy, K., Ray, P., & Brown, C. (2018). Climate risk informed decision analysis (CRIDA): Collaborative water resources planning for an uncertain future. UNESCO and ICIWaRM: Paris and Alexandria.

Moussa, B., Nkonya, E., Meyer, S., Kato, E., Johnson, T., Hawkins, J. (2016). Economics of Land Degradation and Improvement in Niger. In: Nkonya, E., Mirzabaev, A., von Braun, J. (eds) Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Springer: Cham.
OCHA. (2022). Ethiopia: Drought Update No. 2, March 2022. UN Office for the Coordination of Humanitarian Affairs. Retrieved from: https://reliefweb.int/report/ethiopia/ethiopia-drought-update-no-2-march-2022
Plato. (no date). Critias. (B. Jowett, Trans). Retrieved from: http://classics.mit.edu/Plato/critias.html
Potapov, P., Hansen, M. C., Pickens, A., Hernandez-Serna, A., Tyukavina, A., Turubanova, S., ... & Kommareddy, A. (2022). The global 2000-2020 land cover and land use change dataset derived from the Landsat archive: first results. Front. Remote Sens. 3: 856903. doi: 10.3389/frsen.
Ray, P.A., & Brown, C.M. (2015). Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework. World Bank: Washington, DC.
Salati, E., Dall'Olio, A., Matsui, E., & Gat, J. R. (1979). Recycling of water in the Amazon basin: an isotopic study. Water resources research, 15(5), 1250-1258.
Savenije, H. H. (1995). New definitions for moisture recycling and the relationship with land-use changes in the Sahel. Journal of Hydrology, 167(1-4), 57-78.
Scharping, N. (2021). As the Climate Warms, Could the U.S. Face Another Dust Bowl? YaleEnvironment360. Retrieved from: https://e360.yale.edu/features/as-the-climate-warms-could-the-u.s.-face-another-dust-bowl
Sheil, D. (2018). Forests, atmospheric water and an uncertain future: the new biology of the global water cycle. Forest Ecosystems, 5(1), 1-22.
UNDRR & UNECE. (2018). Implementation Guide for Addressing Water-Related Disasters and Transboundary Cooperation: Integrating disaster risk management with water management and climate change adaptation. Words into Action Guidelines. UNDRR: Geneva.
UNECE & INBO. (2015). Water and Climate Change Adaptation in Transboundary Basins: Lessons Learned and Good Practices. UNECE & INBO: Geneva & Paris.
UNEP. (2021). Progress on Integrated Water Resources Management: Global indicator 6.5.1 updates and acceleration needs. UNEP: Nairobi.
Wang, J., Song, C., Reager, J. T., Yao, F., Famiglietti, J. S., Sheng, Y., ... & Wada, Y. (2018). Recent global decline in endorheic basin water storages. Nature geoscience, 11(12), 926-932.

Chapter 3

GCA. (2019). Adapt Now: A Global Call for Leadership on Climate Resilience. Global Center on Adaptation & World Resources Institute: Rotterdam & Washington, DC.
GWP. (2019). Addressing Water in National Adaptation Plans: Water Supplement to the UNFCCC NAP Technical Guidelines. Global Water Partnership: Stockholm.
Murray, V., Maini, R., Clarke, L., & Eltinay, N. (2017). Coherence between the Sendai Framework, the SDGs, the Climate Agreement, New Urban Agenda and World Humanitarian Summit, and the role of science in their implementation. Proceedings of the Global Platform for Disaster Risk Reduction, Cancun, Mexico, 24-26.
NDC Partnership. (2019). Applying Knowledge to Implement Disaster Risk Reduction. Retrieved from: https://ndcpartnership.org/news/applying-knowledge-implement-disaster-risk-reduction
NDC Partnership. (2020). Adaptation and the NDCs. Insight Brief. NDC Partnership: Washington, DC. Retrieved from: https://ndcpartnership.org/news/insight-brief-highlights-ndc-enhancement-progress
OECD. (2020). Common Ground Between the Paris Agreement and the Sendai Framework: Climate Change Adaptation and Disaster Risk Reduction. OECD: Paris.
RCRCCC. (2022). Disaster risk reduction in national climate action – a new analysis. Retrieved from: https://www.climatecentre.org/7685/disaster-risk-reduction-in-national-climate-action-a-new-analysis/
Timboe, I., Pharr, K., & Matthews, J.H. (2020). Watering the NDCs: National Climate Planning for 2020—How water-aware climate policies can strengthen climate change mitigation & adaptation goals. AGWA: Corvallis.
UNDRR. (2021). Promoting Synergy and Alignment Between Climate Change Adaptation and Disaster Risk Reduction in the Context of National Adaptation Plans: A Supplement to the UNFCCC NAP Technical Guidelines. UNDRRR: Geneva.
WMO. (2021a). Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019). WMO: Geneva.
WMO. (2021b). 2021 State of Climate Services: Water. WMO: Geneva.

Chapter 4

ARC. (2021). African Risk Capacity - Sovereign Disaster Risk Solutions. Retrieved from: https://www.unisdr.org/files/globalplatform/officialstatementafricanriskcapacit.pdf
Asian Development Bank. (2015). Water-Related Disasters and Disaster Risk Management in the People's Republic of China. ADB: Manila. https://www.adb.org/sites/default/files/publication/177695/water-related-disasters-prc.pdf
Bakkensen, L., & Barrage, L. (2017). Flood risk belief heterogeneity and coastal home price dynamics: Going under water? National Bureau of Economic Research: Cambridge, MA. https://doi.org/10.3386/w23854
BMZ. (2021). InsuResilience Global Partnership: insuring against the impact of climate change. Retrieved from: https://www.giz.de/en/worldwide/81563.html
CDP. (2021). A wave of change: The role of companies in building a water-secure world. CDP Global Water Report 2020. CDP Worldwide: London. https://www.cdp.net/en/research/global-reports/global-water-report-2020
CDP & Planet Tracker. (2022). High and Dry - How water issues are stranding assets. CDP Worldwide: London. https://www.cdp.net/en/research/global-reports/high-and-dry-how-water-issues-are-stranding-assets
Dewey, S. (2022). What to know about the SEC's Proposed Climate Risk Disclosure Rule. Harvard Environmental & Energy Law Program. Retrieved from: https://eelp.law.harvard.edu/2022/04/what-to-know-about-the-sec-proposed-climate-risk-disclosure-rule/
Dikau, S., & Volz, U. (2021). Central Bank mandates, sustainability objectives and the promotion of Green Finance. Ecological Economics, 184, 107022. https://doi.org/10.1016/j.ecolecon.2021.107022
EM-DAT. (2019). The International Disasters Database. Retrieved from: https://www.emdat.be/.
Environment Agency. (2014). Flood and Coastal Erosion Risk Management Outcome Measures. Retrieved from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/389952/FCERM_outcome__measures_Q2_2014_15__External.pdf.
FAO. (2020). The State of Food and Agriculture 2020. Overcoming water challenges in agriculture. FAO: Rome. https://doi.org/10.4060/cb1447en.
Four Twenty Seven. (2020). Measuring What Matters: A New Approach to Assessing Sovereign Climate Risk. http://427mt.com/wp-content/uploads/2020/12/Measuring-What-Matters-Sovereign-Climate-Risk-427_12.2020.pdf
Gallagher, J. (2014). Learning about an infrequent event: Evidence from flood insurance take-up in the United States. American Economic Journal: Applied Economics, 6(3), 206–233. https://doi.org/10.1257/app.6.3.206
Hallegatte, S., Vogt-Schilb, A., Bangalore, M., & Rozenberg, J. (2017). Unbreakable: Building the resilience of the poor in the face of natural disasters. World Bank Group: Washington, DC. https://openknowledge.worldbank.org/handle/10986/25335
wHanger, S., Linnerooth-Bayer, J., Surminski, S., Nenciu-Posner, C., Lorant, A., Ionescu, R., & Patt, A. (2018). Insurance, public assistance, and Household Flood Risk Reduction: A comparative study of Austria, England, and Romania. Risk Analysis, 38(4), 680–693. https://doi.org/10.1111/risa.12881
Healy, A., & Malhotra, N. (2009). Myopic voters and natural disaster policy. American Political Science Review, 103(3), 387–406. https://doi.org/10.1017/s0003055409990104
HELP & OECD. (2019). Background Note for Principles on Investment and Financing for Water-related Disaster Risk Reduction. Retrieved from: https://www.wateranddisaster.org/cms310261/wp-content/uploads/2019/07/HELP-Principles-Full-Final-Printing.pdf.
Hino, M., & Burke, M. (2021). The effect of information about climate risk on property values. Proceedings of the National Academy of Sciences, 118(17). https://doi.org/10.1073/pnas.2003374118
Houben, S., Schellekens, G., & Zander, K. (2021). The clock is ticking for banks to manage climate and environmental risks. European Central Bank - Banking supervision. https://www.bankingsupervision.europa.eu/press/publications/newsletter/2021/html/ssm.nl210818_5.en.html.
IPCC. (2018). Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press: Cambridge & New York. doi:10.1017/9781009157940.001.
ISDR. (2011). Global Assessment Report on Disaster Risk Reduction 2011: Revealing Risk, Redefining Development. UNDRR. https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2011
Kellett, J., & Caravani, A. (2013). Financing Disaster Risk Reduction: A 20 Year Story of International Aid. GFDRR and ODI. https://www.gfdrr.org/sites/default/files/publication/Financing-DRR_Publication_0.pdf
Kellett, J., Caravani, A., & Pichon, F. (2014). Financing disaster risk reduction: towards a coherent and comprehensive approach. ODI and UNDP. https://cdn.odi.org/media/documents/9027.pdf
Kölbel, J., Strong, C., Noe, C., & Reig, P. (2018). Mapping Public Water Management by Harmonizing and Sharing Corporate Water Risk Information. Technical note. WRI: Washington, DC. https://www.wri.org/research/mapping-public-water-management-harmonizing-and-sharing-corporate-water-risk-information
Mechler, R. (2016). Reviewing estimates of the economic efficiency of Disaster Risk Management: Opportunities and limitations of using risk-based cost–benefit analysis. Natural Hazards, 81(3), 2121–2147. https://doi.org/10.1007/s11069-016-2170-y
Mechler, R., Czajkowski, J., Kunreuther, H., Michel-Kerjan, E., Botzen, W., Keating, A., McQuistan, C., Cooper, N., & O'Donnell, I. (2014). Making communities more flood resilient: The role of cost benefit analysis and other decision-support tools in disaster risk reduction. White Paper. Zurcih Flood Resilience Alliance. https://pure.iiasa.ac.at/id/eprint/11193/
Mekonnen, M. M., & Hoekstra, A. Y. (2016). Four billion people facing severe water scarcity. Science Advances, 2(2). https://doi.org/10.1126/sciadv.1500323
Multi-Hazard Mitigation Council. (2005). Natural hazard mitigation saves: an independent study to assess the future savings from mitigation activities: Volume 1 – Findings, Conclusions, and Recommendations. National Institute of Building Sciences: Washington, DC. https://www.nibs.org/files/pdfs/hms_vol1.pdf
Multi-Hazard Mitigation Council. (2019). Natural Hazard Mitigation Saves: 2019 Report. National Institute of Building Sciences: Washington, DC. https://www.nibs.org/files/pdfs/NIBS_MMC_MitigationSaves_2019.pdf
Naik, G. (2021). Water stress is the main medium-term climate risk for Europe's biggest economies. S&P Global. Retrieved from: https://www.spglobal.com/esg/insights/water-stress-is-the-main-medium-term-climate-risk-for-europe-s-biggest-economies
NGFS. (2019). Guide to climate scenario analysis for central banks and supervisors. Technical Document. Network for Greening the Financial System. https://www.ngfs.net/sites/default/files/medias/documents/ngfs_guide_scenario_analysis_final.pdf
OECD. (2014). Boosting Resilience through Innovative Risk Governance. OECD Reviews of Risk Management Policies. OECD Publishing: Paris. http://dx.doi.org/10.1787/9789264209114-en
OECD. (2015a). Financial management of disaster risks, in "Disaster Risk Financing: A global survey of practices and challenges". OECD Publishing: Paris. https://doi.org/10.1787/9789264234246-4-en
OECD. (2015b). Water and cities. OECD Publishing: Paris. https://www.oecd.org/env/water-and-cities-9789264230149-en.htm
OECD. (2016). Financial Management of Flood Risk. OECD Publishing: Paris. https://doi.org/10.1787/9789264257689-en
OECD. (2018a). Assessing the Real Cost of Disasters: The Need for Better Evidence. OECD Publishing: Paris. https://doi.org/10.1787/19934106
OECD. (2018b). Climate-resilient infrastructure. OECD Environment Policy Papers. No. 14, OECD Publishing: Paris. https://dx.doi.org/10.1787/4fdf9eaf-en

OECD. (2018c). Developing Robust Project Pipelines for Low-Carbon Infrastructure. OECD Publishing: Paris. https://dx.doi.org/10.1787/9789264307827-en

OECD. (2019). Land Value Capture: Framework and Instruments. Unpublished paper. https://www.oecd-ilibrary.org/urban-rural-and-regional-development/global-compendium-of-land-value-capture-policies_4f9559ee-en

OECD. (2021a). Investigating the financial materiality of water. 8th Roundtable on Financing Water: Thematic meeting focused on Climate Action. https://www.oecd.org/water/Background-paper-RT-on-Financing-Water-and-Climate-Action-Session-3.pdf

OECD. (2021b). Managing Climate Risks, Facing up to Losses and Damages. OECD Publishing: Paris. https://doi.org/10.1787/55ea1cc9-en.

OECD. (2022a). Building financial resilience to climate impacts - A framework for government action to manage the risks of losses and damages. Unpublished. https://www.oecd.org/stories/climate-change/en/resources

OECD. (2022b). EC DG Environment Initiative on the Economic Aspects of Implementing the EU Water Framework and Floods Directives. Cost recovery - Background note for the OECD-EC workshop series on the economics of the WFD. Unpublished. https://www.oecd.org/water/dg-env-economics-of-wfd.htm

OECD. (2022c). Financing a Water Secure Future. OECD Studies on Water. OECD Publishing: Paris. https://doi.org/10.1787/a2ecb261-en

OECD and Lincoln Institute of Land Policy. (2022). Global compendium of land value capture policies. OECD Publishing: Paris. https://doi.org/10.1787/4f9559ee-en

Ovink, H., Schous, J., Declerck, J., van Godsenhoven, S., Vandemoortel, B., Naudts, N., ... & Arts, J. (2021). Water as Leverage- Reflect. Government of the Netherlands. https://drive.google.com/file/d/1s9tNlk9VCLwtXakQ6-POKPlY4W6P112v/preview

Pilla, F., Gharbia, S. S., & Lyons, R. (2019). How do households perceive flood-risk? the impact of flooding on the cost of accommodation in Dublin, Ireland. Science of The Total Environment, 650, 144–154. https://doi.org/10.1016/j.scitotenv.2018.08.439

Sandink, D. (2015). Urban flooding and ground-related homes in Canada: An overview. Journal of Flood Risk Management, 9(3), 208–223. https://doi.org/10.1111/jfr3.12168

Shao, W., Xian, S., Lin, N., Kunreuther, H., Jackson, N., & Goidel, K. (2017). Understanding the effects of past flood events and perceived and estimated flood risks on individuals' voluntary flood insurance purchase behavior. Water Research, 108, 391–400. https://doi.org/10.1016/j.watres.2016.11.021

Storey, B., Owen, S., Noy, I., & Zammit, C. (2020). Insurance Retreat - Sea Level Rise and the Withdrawal of Residential Insurance in Aotearoa New Zealand. Report for the Deep South National Science Challenge. https://deepsouthchallenge.co.nz/wp-content/uploads/2021/01/Insurance-Retreat-December-2020-Final-Report.pdf

Storey, B., & Noy, I. (2017). Insuring property under climate change. Policy Quarterly, 13(4). https://doi.org/10.26686/pq.v13i4.4603

United Nations. (1976). United Nations Conference on Human Settlements: Habitat I. United Nations. https://www.un.org/en/conferences/habitat/vancouver1976

United Nations. (2020). Climate Action Pathway, Water. Executive Summary. https://unfccc.int/climate-action/marrakech-partnership/reporting-tracking/pathways/water-climate-action-pathway

UNISDR & EM-DAT. (2018). Economic Losses, Poverty and Disasters 1998-2017. https://www.unisdr.org/2016/iddr/IDDR2018_Economic%20Losses.pdf

Vorhies, F., & Wilkinson, E. (2016). Co-benefits of disaster risk management. Policy Research working paper. World Bank Group: Washington, DC. http://documents.worldbank.org/curated/en/746741467986362487/Co-benefits-of-disaster-risk-management

Watson, C., Caravani, A., Mitchell, T., Kellett, J., & Peters, K. (2015). Finance for reducing disaster risk: 10 things to know. ODI: London. https://odi.org/en/sendai-2015-new-global-agreement-disaster-risk-reduction/

World Economic Forum. (2015). The Global Risks 2015 Report (10th Edition). WEF: Geneva. https://www3.weforum.org/docs/WEF_Global_Risks_2015_Report15.pdf

World Food Program. (2018). Arc Replica: WFP's partnership with the African Risk Capacity (ARC) for the expansion of Climate Risk Insurance. Retrieved from: https://docs.wfp.org/api/documents/WFP-0000063792/download/#:~:text=WHAT%20IS%20ARC%20REPLICA%3F

Chapter 5

COVID-19 WBEC. (2023). Summary of Global SARS-CoV-2 Wastewater Monitoring Efforts by UC Merced Researchers. Retrieved from: https://www.covid19wbec.org/covidpoops19

Donoghoe, M.. Sengupta, S., Costella, C., & Sivanu, S. (2022). Climate change, intersecting disasters and social protection: How the COVID-19 experience can prepare us for the future. Red Cross Red Crescent Climate Centre.

Ford, J. D., Zavaleta-Cortijo, C., Ainembabazi, T., Anza-Ramirez, C., Arotoma-Rojas, I., Bezerra, J., ... & Wright, C. (2022). Interactions between climate and COVID-19. The Lancet Planetary Health, 6(10), e825-e833.

Masters, J. (2020). Super Typhoon Goni slams into Philippines as strongest landfalling tropical cyclone on record. Yale Climate Connections. Retrieved from: https://yaleclimateconnections.org/2020/11/super-typhoon-goni-slams-into-philippines-as-strongest-landfalling-tropical-cyclone-on-record/

Mavrouli, M., Mavroulis, S., Lekkas, E., & Tsakris, A. (2022). Infectious Diseases Associated with Hydrometeorological Hazards in Europe: Disaster Risk Reduction in the Context of the Climate Crisis and the Ongoing COVID-19 Pandemic. International journal of environmental research and public health, 19(16), 10206.

Muhumuza, R. (2021). Locusts, COVID-19, flooding pose 'triple threat' in Africa. AP NEWS. Retrieved from: https://apnews.com/article/uganda-deserts-virus-outbreak-health-yemen-4d7f07d32115ce62f02c7c090b49f78e

UNDRR. (2020). UNDRR COVID-19 Brief: Preliminary Evidence from Sub-Saharan Africa, 16 June 2020. UNDRR: Addis Ababa. Retrieved from: https://reliefweb.int/report/world/undrr-covid-19-brief-preliminary-evidence-sub-saharan-africa-16-june-2020

Walton, D., Arrighi, J., van Aalst, M., & Claudet, M. (2021). The compound impact of extreme weather events and COVID-19. IFRC & Red Cross Red Crescent Climate Centre.

Chapter 6

Alaerts, G., Blair, T. J., & Hartvelt, F. (1991). A Strategy for Water Sector Capacity Building. International Institute for Hydraulic and Environmental Engineering & UNDP: Delft & New York City.

Alaerts, G.J., & Kaspersma, J.M. (2023). Facing global transitions in water management: Advances in knowledge and capacity development and towards adaptive approaches. Water Policy 24(5), 685-707.

Andrews, M., Pritchett, L., & Woolcock, M. (2017). Building State Capability: Evidence, Analysis, Action. Oxford University Press: Oxford.

Bryant, B. P., & Lempert, R. J. (2010). Thinking inside the box: a participatory, computer-assisted approach to scenario discovery. Technological Forecasting & Social Change 77, 34–49.

Famiglietti, J. S. (2014). The global groundwater crisis. Nature Climate Change 4, 945–948.

Gleeson, T., Cuthbert, M., Ferguson, G., & Perrone, D. (2020). Global groundwater sustainability, resources, and systems in the anthropocene. Annual Review of Earth and Planetary Sciences 48, 431–463. https://doi.org/10.1146/annurev-earth-071719-055251

Glouberman, S., & Zimmerman, B. (2004). Complicated and complex systems: what would successful reform of medicare look like? In: Romanow Papers: Changing Healthcare in Canada, Vol. 2. [Forest, P. G., Marchildon, G. P. & McIntosh, T. (eds)]. University of Toronto Press: Toronto.

Haasnoot, M., van Aalst, M., Rozenberg, J., Dominique, K., Matthews, J., Bouwer, L. M., ... & Poff, N. L. (2020). Investments under non-stationarity: economic evaluation of adaptation pathways. Climatic change, 161, 451-463.

Haasnoot, M., & Warren, K. (2019). Dynamic adaptive policy pathways (DAPP). In Decision Making Under Deep Uncertainty. [Marchau, V. A. W. J., Walker, W. E., Bloemen, P. J. T. M., & Popper, S. W. (eds)]. Springer Nature: Cham.

Herrera-García, G., Ezquerro, P., Tomás, R., Béjar-Pizarro, M., López-Vinielles, J., Rossi, M., Mateos, R. M., Carreón-Freyre, D., Lambert, J., Teatini, P., Cabral-Cano, E., Erkens, G., Galloway, D., Hung, W. C., Kakar, N., Sneed, M., Tosi, L., Wang, H. M., & Ye, S. J. (2021). Mapping the global threat of land subsidence. Science 6524, 34–36.

IPCC. (2021). Climate change 2021: the physical science basis. In: Contribution of WG I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V. et al., eds]. Cambridge University Press: Cambridge & New York City.

IPCC. (2022). Climate change 2022: impacts, adaptation and vulnerability. In: Contribution of WG II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Partner, H.-O. et al., eds]. World Meteorological Organization & United Nations Environmental Programme: Geneva & Nairobi.

Kwakkel, J. H., Haasnoot, M., & Walker, W. E. (2016). Comparing robust decision-Making and dynamic adaptive policy pathways for model-based decision support under deep uncertainty. Environmental Modelling and Software 86, 168–183. doi:10.1016/j.envsoft.2016.09.017.

Lempert, R. J., Groves, D. G., Popper, S. W., & Bankes, S. C. (2006). A general, analytic method for generating robust strategies and narrative scenarios. Management Science 52(4), 514–528.

McGrath, R. G. (2011). The World is More Complex than it used to be. Harvard Business Review, June–August, 2011. Retrieved from: https://hbr.org/2011/08/the-world-really-is-more-compl.html

OECD. (2012). OECD Environmental Outlook to 2050. OECD Publishing: Paris.

OECD. (2014). Water Governance in The Netherlands. Fit for the Future? OECD Publishing: Paris.

OECD. (2017). The Land-Water-Energy Nexus: Biophysical and Economic Consequences. OECD Publishing: Paris.

OECD. (2019). Biodiversity: Finance and the Economic and Business Case for Action. OECD Publishing: Paris.

O'Rourke, E. (1992). The international drinking water supply and sanitation decade: dogmatic means to a debatable end. Water Science and Technology 26(7–8), 1929–1939. https://doi.org/10.2166/wst.1992.0638.

Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. Water Resources Management 21, 49–62.

Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D., & Taillieu, T. (2007). Social learning and water resources management. Ecology and Society 12(2), 5.

Portmann, F. T. (2013). Impact of climate change on renewable groundwater resources: assessing the benefits of avoided greenhouse gas emissions using selected CMIP5 climate projections. Environmental Research Letters 8(2), 024023. doi:10.1088/1748-9326/8/2/024023.

Sadoff, C. W., Hall, J. W., Grey, D., Aerts, J. C., Ait-Kadi, M., Brown, C., Cox, A., Dadson, S., Garrick, D., & Kelman, J. (2015). Securing Water, Sustaining Growth: Report of the GWP/OECD Task Force on Water Security and Sustainable Growth. University of Oxford: Oxford.

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N. W., Clark, D. B., ... & Kabat, P. (2014). Multimodel assessment of water scarcity under climate change. Proceedings of the National Academy of Sciences, 111(9), 3245-3250.

Snyder, S. (2013). The Simple, the Complicated, and the Complex: Educational Reform Through the Lens of Complexity Theory. Education Working Paper. OECD Publishing: Paris.

Turner, S.W. D., Hejazi, M., Yonkofski, C., Kim, S. H., & Kyle, P. (2019). Influence of groundwater extraction costs and resource depletion limits on simulated global nonrenewable water withdrawals over the twenty-first century. Earth's Future 7, 123–135. https://doi.org/10.1029/2018EF001105.

Van der Ent, R. J., Savenije, H., Schaefli, B., & Steele-Dunne, S. C. (2010). Origin and fate of atmospheric moisture over continents. Water Resources Research 46, W09525. doi:10.1029/2010WR009127.

Van der Esch, S., ten Brink, B., Stehfest, E., Bakkenes, M., Sewell, A., Bouwman, A., Meijer, J., Westhoek, H., & van den Berg, M. (2017). Exploring Future Changes in Land use and Land Condition and the Impacts on Food, Water, Climate Change and Biodiversity: Scenarios for the Global Land Outlook. PBL Netherlands Environmental Assessment Agency: The Hague.

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

WWAP. (2018). World Water Development Report 2018. United Nations World Water Assessment Programme & UNESCO: Paris.

WWF. (2020). Living Planet Report 2020 - Bending the Curve of Biodiversity Loss. Almond, R. E. A., Grooten, M. & Petersen, T. (eds). World Wildlife Fund: Gland.