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KNOWLEDGE NOTES

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The Role of Green Infrastructure Solutions in Urban Flood Risk Management

SUMMARY

Rapid urbanization, concentration of economic activity, and climate change are magnifying risks of major disasters in urban settings around the world. Unplanned development, competition for space in dense urban agglomerations, and environmental degradation often result in choking of floodplains and natural catchment areas of rivers and coastal zones. Natural disasters have a disproportionate impact on the urban poor, who often live in informal settlements in vulnerable parts of urban centers.

For a long time, governments implemented hard engineering or gray solutions such as dams and levees to mitigate food risk. However, with adverse impacts of floods growing, interest in a more integrated approach to urban flood risk management is growing as well. **Green infrastructure (GI) solutions** have emerged as a key component of this integrated approach. GI solutions include wetlands, bioshields, buffer zones, green roofing, street side swales, porous pavements, wetlands, mangroves, etc.

> GI is an approach that focuses on using natural processes for managing wet weather impacts while delivering environmental, social, and economic benefits.

While advanced economies have made progress in incorporating these solutions for several decades, interest in GI is rising in developing countries as well. In many countries, legal and regulatory frameworks support adoption of GI solutions. The literature offers substantial guidance on calculating costs and benefits, which decision makers may need in order to incorporate GI solutions as part of broader urban flood risk management plans. Not surprisingly, countries also face impediments to take-up of GI solutions.

The note highlights the impact of floods on the urban poor. **Ninety percent of new urban residents are in Africa and Asia**, which have some of the poorest countries in the world. Many new urban residents end up in informal settlements, often in locations vulnerable to natural hazards such as floods. In this context, it is imperative that urban poor have a voice in how cities manage disaster risk. By creating awareness of the full range of options for flood risk management, city officials can help develop sustainable solutions with support of local communities. Even leaving their economic and safety benefits aside, GI solutions have social benefits that can be particularly useful to poor urban communities. Clean air, pleasant surroundings, and a reduced heat island effect, for example, can add much value to the lives of urban poor. More importantly, less pollution in urban water systems can disproportionately benefit the poor given that better-off sectors of society may have access to clean drinking water beyond municipal supply systems.

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CASE STUDIES presented in this note provide an opportunity for practitioners to review lessons of international experience. Based on these, the note provides recommendations on how to implement GI solutions. It also considers some impediments to implementation and illustrates how they might be addressed. Some gaps in the knowledge base remain, however. International institutions such as the World Bank can help plug these gaps. Promoting GI solutions will involve creating awareness within the disaster risk management community, partnering with other disciplines (such as urban development, governance, environmental services, etc.), and combining lessons built on international experience with strong technical know-how and a robust evidentiary knowledge base.

INTRODUCTION

Around the world, a major demographic transformation is taking place.

An increasing number of people are leaving their homes in rural areas and flocking to urban centers. In 1950, about a third of the world's population lived in cities. Today cities are home to over half the world's population. This transition continues relentlessly, driven by economic opportunities. According to the consulting firm McKinsey and Company, 60 percent of global gross domestic product (GDP) is produced in only 600 urban centers, and this concentration of economic activity in urban areas is expected to grow *(McKinsey and Company 2011)*. Concurrently, the rural-urban transition of population will also become more pronounced, with almost two-thirds of the world's population living in urban areas by 2050 *(UN 2015)*.

The quality and scale of this demographic shift has profound implications for countries around the world.

While urban development and planning must be geared toward managing this shift, the agglomeration of economic activities and people creates certain risks that must be accounted for as this process unfolds. As urban centers become denser due to economic activity and population growth, the likelihood of natural hazards inflicting heavier economic and human losses grows. What further complicates this picture is the growth of informal settlements where urban poor tend to concentrate. With land under pressure, these settlements develop in floodplains, in coastal zones, on steep hills, and in other areas vulnerable to natural hazards such as flooding, sea-level rise, landslides, etc. Many studies have noted that climate change exacerbates risks associated with these hazards. As a result, not only are urban populations at growing risk, it is the urban poor who may be especially vulnerable to disasters linked to natural hazards *(World Bank 2012a)*.

Human and economic impacts of natural disasters, especially those related to weather and climate, are rising.

According to the 2015 Global Assessment Report *(UNISDR 2015)*, natural disasters lead to economic losses of almost US$250 billion each year. Over the last 20 years, 90 percent of all disasters have been weather-related, and of these, flooding alone accounts for almost half. These floods affected 2.3 billion people, 95 percent of whom were located in Asia. Within this context, the focus on urban environments and populations is necessary. With 70 million people moving to urban slums each year, the scale of the challenge becomes clearer. By 2030, 2 billion people will inhabit urban slums, a doubling of the current 1 billion. Most of this growth is likely to occur close to coastal zones, floodplains, and other areas vulnerable to hazards (World Bank 2012a). Biodiversity is under pressure, and issues such as water scarcity and drought are of increasing concern to policy makers and local communities alike. Climate change is likely to increase the risk of these hazards turning into devastating disasters. Massive floods—such as those in Nigeria (2012), Thailand (2013), southeastern Europe (2014), and South Carolina, United States (2015)—are causing huge human and economic losses. Beyond these mega-events, each year there are hundreds of floods around the world that don't receive much public scrutiny. A related matter that appears to receive even less attention is the choice of measures to reduce the risk of these floods or at least the losses associated with them.

With greater awareness of urban disaster risk, experts are beginning to focus attention on strengthening the resilience of cities.

For instance, the "Making Cities Resilient" campaign initiated by the UNISDR and UN-HABITAT promotes resilience to urban risk for local government and encourages sustainable urbanization principles. According to these agencies, a "resilient city is characterized by its capacity to withstand or absorb the impact of a hazard through resistance or adaptation, which [enables] it to maintain certain basic functions and structures during a crisis, and bounce back or recover from an event" *(UNISDR 2012b, 11)*. The campaign proposes 10 essentials for making a city resilient, one of which specifically focuses on environmentally sustainable practices. Citing the increased risk of flooding and landslides associated with urbanization of watersheds, the campaign asserts: "Maintaining a balance between human actions and the environment is an excellent strategy for reducing risk and contributing to resilience and sustainability" *(UNISDR 2012a)*.

Traditional infrastructure solutions for flood risk management are no longer sufficient.

The standard tools of flood risk management have been engineering infrastructure solutions such as dams, levees, drains, pumping stations, walls, etc. Around the world, billions of dollars are spent each year fortifying against the impact of floods with the help of this gray infrastructure. While gray infrastructure solutions are needed in many situations, they are not a panacea, and they can in some cases actually increase flood risk—for example, if they disconnect rivers from their surrounding floodplains *(Nature Conservancy 2014)*. In such cases, there is a loss of other ecosystem services such as water purification by soil (water is instead discharged directly to surface water), a loss of (temporal) production area because of the spatial claim of infrastructure, a loss in landscape value (which may hamper touristic value), and loss in water quantity regulation (as a result of increased fluctuation in discharge). Gray infrastructure provides little flexibility/adaptability to address future uncertainties. It can also be expensive and isn't always within reach for governments and communities in the developing world. In the aftermath of Hurricane Katrina, New Orleans spent US$14 billion to strengthen its levee system. For perspective, that amount is greater than the annual GDP of almost 70 countries. Having said this, it is important to underline that gray infrastructure is required in many situations as part of an integrated flood management system. Lessons from Vietnam suggest an approach to risk mitigation that incorporates flexibility to deal with uncertainties in population and asset growth by combining green and gray infrastructure *(World Bank 2012c)*.

GI has emerged as an exciting approach to urban flood risk management.

The exploration of complementary approaches to gray infrastructure has led researchers, practitioners, and policy makers to GI solutions. The underlying principle for GI is to consider the overarching hydrological processes across the catchment area of a river or a coast. The focus is on developing GI capacity that retains stormwater in natural storage areas and prevents water from flooding sewer systems and waterways. It should be noted that GI in the context of flood risk management is quite different from GI in the context of energy. The latter includes renewable energy infrastructure such as solar panels and windmills. In this Knowledge Note, we refer to GI solutions in the context of flood risk management only. One important point to reiterate is that this note does not argue for GI solutions as a full alternative to gray infrastructure. We look at GI as a complement to traditional solutions and as part of a broader, more holistic, and more integrated flood risk management system *(World Bank 2011)*.

THE REST OF THIS KNOWLEDGE NOTE IS ORGANIZED AS FOLLOWS:

IN SECTION 2, we introduce GI solutions and explain how they work and what benefits they provide.

IN SECTION 3, we review issues around implementation of GI solutions. Case studies are presented

IN SECTION 4, we illustrate a variety of GI solutions, while impediments to adopting these solutions are considered.

IN SECTION 5. Finally, a **CONCLUDING SECTION** provides recommendations on overcoming impediments, identifies gaps, and provides suggestions for further work for practitioners as well as for institutions such as the World Bank.

BENEFITS OF GREEN INFRASTRUCTURE SOLUTIONS

Understanding different components of urban flood risk is important.

When rain falls in a nonurban environment such as a forest, about 50 percent of the water seeps into the ground. This process recharges groundwater. Estimates indicate that 40 percent of the rainwater goes back into the atmosphere through a process called evapotranspiration. The remaining 10 percent is surface runoff. The picture is very different in urban areas, where up to half the area does not allow rainwater to seep into the ground. This is due to impervious surfaces such as roads, roofs, parking areas, sports facilities, etc. Obviously, urban areas in more developed economies may have a higher share of built up areas with hard surfaces. Since the ground is unable to absorb rainwater, the water flows directly into rivers, streams, and sewers. The United States Environmental Protection Agency (EPA) estimates that a typical American city block. "generates five times more runoff than a woodland area of the same size, while only about 15 percent [of rainwater] infiltrates into the ground for groundwater recharge" *(Copeland 2014, 1)*. During major rainfall events, this additional runoff overwhelms rivers, streams, and sewers and causes severe flooding. Additional risks include drought (due to reduced groundwater recharge and reduced surface water storage) and negative impacts on water quality.

There is growing interest in GI solutions for managing risks.

The combination of increasing flood risk, potential for major human and economic losses, and unevenness in the efficacy and costs of gray infrastructure has led to growing interest in exploring other approaches. GI solutions focus on managing wet-weather impacts by using natural processes. As part of an integrated flood risk management framework, they can also deliver environmental, social, and economic benefits, and can be cost-effective, low in impact, and environmentally friendly (sustainable). In contrast, traditional approaches such as levees and dams focus on changing the flow of rivers and streams to protect local communities, and use piped drainage systems in urban areas to quickly move storm water away from the built environment. As an unintended consequence, fast drainage of water may result in drought problems, and drought may reduce the ability of existing green spaces to provide important services such as reducing heat stress.

GI solutions provide a complementary approach that reduces the flow of stormwater by connecting it to adjacent natural storage and overflow systems.

Gray infrastructure solutions remain a key component of flood risk management frameworks and are necessary in many situations. But GI solutions can be a valuable part of an integrated approach. GI solutions include among others wetlands, bioshields, buffer zones, green roofing, tree pits, street side swales, porous pavements, and use of green materials (wood, bamboo, coconut nets, etc.). These measures not only help reduce flood impacts but also produce environmental and health benefits. **Box 2.1 provides examples of GI solutions.**

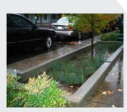
Box 2.1 Examples of Green Infrastructure Solutions

Bioswales

Broad and shallow vegetated, mulched, or landscaped channels that provide stormwater treatment and retention. They slow water flows and allow for infiltration, thereby filtering stormwater flows.

Green roofs

Roofs covered with vegetation. They are cost-effective in dense urban areas with high land values and can help reduce the heat island effect

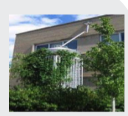


Planter boxes

Structures with vertical walls and open or closed bottoms filled with gravel, soil, and vegetation that collect and absorb runoff. They are ideal for space-limited sites.

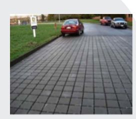
Rain gardens

Shallow, vegetated basins that collect and absorb runoff through infiltration and evapo-transpiration. Also known as bioretention or bio-infiltration cells, they can be installed in nearly any unpaved space.



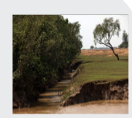
Rainwater harvesting

Systems that collect and store rainfall for later use. These systems provide a renewable water supply and can slow and reduce runoff. Such systems can reduce demands on increasingly limited water supplies in arid regions.



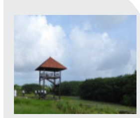
Permeable pavements

Porous paved surfaces that allow rain to infiltrate into soils. Permeable pavements can be constructed from various materials such as pervious concrete, porous asphalt, and permeable interlocking pavers.



Mangroves

Group of trees or shrubs in coastal areas. Restoration of mangroves can help create a natural barrier to reduce risk of coastal flooding.



Wetlands

Areas where water covers the soil or is present either at or near the surface of the soil all year or for varying periods during the year. By absorbing excess water, wetlands can help prevent major flooding in urban areas.

Source: Text adapted from U.S. EPA, "What Is Green Infrastructure," https://www.epa.gov/green-infrastructure/what-green-infrastructure (accessed November 2, 2015). All photos are from the U.S. EPA website, https://www.epa.gov/green-infrastructure/what-green-infrastructure except for those of mangroves and wetlands which are from the World Bank:

GI has multiple benefits.

First and foremost, it can reduce the risk of urban flooding by controlling surface runoff. With less water flowing into rivers and sewer systems, flood risk is naturally reduced. GI also allows for a more controlled process of evapotranspiration in the catchment area, which drains the water associated with rainfall and rivers in an urban settlement. GI allows, too, for the possibility of groundwater recharge. The lower risk of flooding entails clear economic benefits, and the cost of GI solutions themselves is relatively low. Proponents suggest that not only is GI less expensive to develop than comparable gray infrastructure, but it can be less expensive to maintain as well. Specifically, GI can be up to 30 percent cheaper to construct and 25 percent less costly over its life span than comparable traditional infrastructure *(Kloss and Calarusse 2006; Garrison and Hobbs 2011).*

Beyond economic benefits, GI can deliver important benefits for health and well-being.

In urban areas, surface runoff may include many pollutants that can infiltrate a city's water supply or water bodies used for recreation. Since GI reduces surface runoff, increasing its use offers potential public health benefits. There is also the potential to save energy as a result of using GI. For example, green roofs can provide insulation and reduce heating and cooling costs for buildings. Water harvesting can not only reduce water bills for consumers but can also reduce the demand pressures facing utilities around the world. Other potential benefits include improved air quality, reduced heat island effects, pleasant livable spaces, more recreational spaces for urban residents, and availability of habitat for wildlife in the vicinity of urban centers.

GI can have a very positive impact on urban poor.

To the extent that GI investments can mitigate flood risk in vulnerable communities, the positive impact on the poor is obvious; since the urban poor are disproportionately impacted by floods and other disasters, it stands to reason that efforts to mitigate disaster risk are likely to benefit the poor. But that is only part of the story. There are tangible economic and social benefits in including GI as part of an overall urban development and planning strategy. It is important to keep in mind that disaster risk mitigation may not always be the primary objective of city planners who are considering investing in GI. The primary motivation may also be to improve different aspects of urban living, such as water quality, sanitation, and air quality, with risk management as a secondary benefit.

GI has economic benefits for developed countries and those moving toward a service-oriented economy.

Much of the literature on documented economic benefits of GI draws on the experience of developed countries. Studies indicate that GI can help promote an economic climate that attracts high-value businesses and professionals *(Molla 2015).* This finding is primarily based on the assumption that GI helps reduce air and water pollution and creates pleasant living spaces. Economic benefits may be more visible in communities that are transitioning over to "new" economic models with more service industry orientation (Michigan State University 2008). Rejuvenation of economic growth can help grow businesses, create job opportunities, and reduce the economic disadvantages that so often accompany rapid urbanization *(Forest Research 2010).*

GI solutions could be part of an effort to address the poverty impacts of poverty's rapid urbanization.

Ninety percent of new urban residents are in Africa and Asia, two regions home to some of the poorest countries in the world. More than half the world's population lives in the same urban centers where much of the global economic activity is focused, and this proximity creates a tantalizing opportunity to reduce poverty and promote shared prosperity. Yet it is also true that poverty is rapidly urbanizing as large numbers of people migrate to cities. With the projected exponential growth of slum dwellers, the usual economic deprivations of the urban poor will be compounded by an additional, disproportionate risk associated with natural hazards, particularly floods (World Bank 2015). **Box 2.2 describes the micro-impacts of major flooding on poor urban populations.**

Box 2.2. Micro-Impacts of Flooding on Urban Poor: Bangkok 2012

What is sometimes lost in the focus on big-picture impacts of major floods is the multitude of smaller stories that lie underneath. A study monitoring the impact on the informal economy of a variety of socioeconomic forces looked at the impact of floods on Bangkok's informal workers.

In one of the focus groups used for the study, a snack-food seller reported:...

"During the big floods last year, my house was underwater and we could not work for more than two months. We had no money to repair the flood damage and no money to restart our business and had to borrow from the moneylender by using our house as collateral."

As reported in another focus group, a few...

"were able to grow vegetables and catch fish in the canals."

Others cooked and ate less food...

"I used to cook two dishes to have with the rice, but when I had no job, I cooked only one dish. I couldn't share my food with my neighbors, which is our normal practice,"

...said one participant, while another noted,

"I reduced both the quantity and quality of what I would buy. I would buy only half the normal amount."

Source: Chen 2014.

GI can provide a source of supplementing incomes.

For poorer populations, food consumption is usually a big part of household budgets. Thus GI that facilitates urban agriculture can provide direct economic benefits to at least some sections of the urban poor *(Mpofu 2013)*. The biggest economic benefits for the urban poor may come from cost savings for local governments as a result of investing in GI. Local governments need evidence to evaluate the cost-effectiveness of GI, but results of some studies indicate that GI solutions can prove cost-effective for local governments. For example, a study by the U.S. Environmental Protection Agency found that in most cases "implementing well-chosen LID (low impact design) practices saves money for developers, property owners, and communities while also protecting and restoring water quality" *(U.S. EPA 2007, iii)*. For policy makers and local government officials, these cost savings can free up resources to boost spending on social infrastructure such as health and education, which poorer communities depend on. Other benefits accrue from reducing flood water runoff. Studies indicate that reduced runoff and flood risk can increase property values and also help avoid costs associated with downstream gray infrastructure investments designed to deal with surface runoff. For small flood events—those that receive little attention and exact recurrent costs—this type of flood control has proved cost-effective *(Johnston, Braden, and Price 2006; American Rivers et al. 2012)*.

Cost-effective GI solutions can create budgetary space for city officials to enhance poverty reduction programs.

Clearly, there are significant socioeconomic benefits of GI that can accrue to urban communities. It isn't always possible to separate out the positive impacts on the urban poor. To the extent that GI investments are cost-effective and reduce disaster-related losses for local governments, disadvantaged groups can benefit if savings are used for poverty reduction and social infrastructure spending. Health benefits are more in the form of public goods, but even here the benefits for urban poor can be disproportionately higher simply because the status quo in rapidly growing and unplanned urban environments is biased against marginalized communities.

GI solutions have social as well as economic benefits.

Green spaces provide a source of relaxation and well-being. Offering a range of opportunities from recreation to relaxation and social interaction, GI can be supportive of a healthy lifestyle in stressed urban communities. This is because people usually satisfy their recreational needs within or close to the localities they live in (Bilgili and Gökyer 2012). In the United Kingdom, studies indicate that green corridors that connect town centers to suburban areas provide opportunities for people to use nonmotorized transport such as bicycles. Mexico City's Chapultepec Park—a large green space within urban surroundings—attracts 15 million visitors each year, who enjoy a wide variety of activities that the park has to offer (Haq 2011). Studies show that even passive usage or simple access to green spaces can be beneficial to mental well-being *(Forest Research 2010)*. Positive benefits for people living in deprived urban communities have also been documented. GI can support an active lifestyle and help reduce the risk of obesity, just as disconnection from the natural environment can cause social isolation, obesity, and chronic stress.

GI helps prevent pollutants from entering city water systems.

If fewer pollutants enter rivers, streams, and coastal water, there are greater opportunities for safely using the water for recreational activities such as swimming and fishing. In the United States, up to 3.5 million people fall sick each year due to contact with water contaminated by sewage *(American Rivers et al. 2012)*. The reduction in pollutants due to GI can lessen such adverse impacts.

IMPLEMENTATION OF GREEN INFRASTRUCTURE SOLUTIONS

This section focuses on implementation of GI solutions.

The issues described here relate to policy and regulatory frameworks that guide implementation in different countries as well as to the role of communities in GI implementation. We also view GI implementation from the perspective of gender issues. To illustrate how GI solutions are implemented under diverse circumstances, several case studies are presented.

POLICY AND REGULATORY FRAMEWORKS

In many advanced economies, there is increasing pressure to more carefully examine structural changes to rivers and coastlines.

For example, in the **European Union**, specific legislation requires officials to evaluate the feasibility of employing "environmental options" rather than making changes in rivers or coasts that can lead to a "deterioration of the status of these waters." In **Germany**, nature protection and building codes require restoration of any natural landscapes and environmental services that are adversely impacted by greenfield projects *(Beuhler et al. 2011)*. In the United States, the Environmental Protection Agency has extensive guidelines on design and implementation of infrastructure solutions that go beyond traditional engineering. In Japan, extensive work on over 23,000 river and wetland restoration projects over a 15-year period demonstrates alternate approaches to issues related to urbanization and environmental management. This work is closely linked to flood protection and other environmental issues (Nakamura, Tockner, and Amano 2006).

Singapore has been a leader in employing GI solutions. Through its Active, Clean, Beautiful (ABC) Waters program, Singapore continues to stay ahead of the curve on issues of sustainable development. The underlying approach of ABC Waters is to treat stormwater as close to its source as possible before discharging the treated water into public drains. The **United Kingdom** passed the Flood and Water Management Act (2010) essentially in response to the 2007 floods. This law promotes flood risk management through the use of natural processes and requires developers to include sustainable drainage in new developments. In accordance with the law, the **United Kingdom** has established national standards aimed at mitigating damage due to floods and improving water quality. In the **United States**, the Environmental Protection Agency has substantial regulatory powers under the Clean Water Act and uses an array of policy tools to specifically promote GI solutions. Policy memos, permits, enforcement orders, etc., encourage municipal authorities to apply GI solutions for managing stormwater and reducing flood risk. In **South Australia**, a focus on water-sensitive urban design "promotes the sustainable use and re-use of water in urban development and buildings". The government is an active backer of this approach as it combats droughts and prepares for potential water insecurity in the future.

In emerging economies, legal and regulatory frameworks in support of GI solutions are less evident.

However, awareness of climate change and increased disaster risk is inspiring a reexamination of risk management frameworks. Much of the focus of disaster risk reduction efforts is on traditional engineering solutions, but countries like **China** have instituted policies and frameworks that take a broader view of flood management. Coupled with the 1997 Flood Control Law, the 2005 national flood management strategy encourages nonstructural methods as complements to structural techniques. **Bangladesh** is also beginning to explore solutions that do not rely on traditional engineering. Dhaka, one of the most flood-prone cities in the world, lost 30 percent of its water bodies to urbanization between 1960 and 2008, and the wetlands adjacent to Dhaka shrank from 5.85 km2 to 3.95 km2. Comprehensive solutions are being explored within the government, such as by the Dhaka Water and Sewerage Authority, which has highlighted the importance of a stormwater drainage master plan that includes restoration of water bodies.

ROLE OF COMMUNITIES IN GREEN INFRASTRUCTURE IMPLEMENTATION

Community participation will strengthen sustainability of GI solutions.

It has almost become a truism in development economics to say that community participation will strengthen development programs. In disaster risk management (DRM) literature, institutions such as the World Bank, Global Facility for Disaster Reduction and Recovery, and UNISDR actively promote community-based or community-driven risk management programs *(World Bank 2013)*. However, in the case of GI this approach requires extra effort. Not only have government officials and development practitioners become used to the idea of gray infrastructure solutions, but these solutions are also ingrained in the broader public consciousness. Instinctively, building a levee seems like a good idea to protect against a river overflowing its banks, whereas a more holistic approach of absorption in the catchment area might seem far-fetched. GI solutions require active consultations with and education of beneficiary populations. Communities may even have an ongoing role in maintaining GI, and success will likely depend on civil society engagement and cooperation with local governments

Gender issues must be considered in any comprehensive DRM framework.

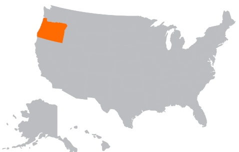
Although it may seem that natural disasters impact men and women identically, this is not necessarily so. Because of physiological differences and cultural norms across societies, disasters can disproportionally impact women and girls. For example, during a major disaster event, women may be reluctant to seek shelter because shared communal facilities sometimes lack separate private spaces. Women may also feel uncomfortable because their clothing is damaged, or because it is culturally impermissible to inhabit mixed-gender spaces. Girls may also have limited opportunities to learn lifesaving skills such as swimming or tree climbing. Sex-disaggregated data from two major disasters tends to support the hypothesis that women can be disproportionately affected by major calamities. In the 1991 cyclone and flood in Bangladesh, female deaths outnumbered male deaths 14 to 1. Similarly, 61 percent of people killed during Cyclone Nargis (2008) in Myanmar were women and girls. More recent analysis of Serbia's 2014 floods indicates that single mothers and women who live alone in their households are among the most vulnerable to natural disasters (OSCE 2015).

Efforts to include gender issues in risk management are slowly making headway.

Traditional gender-based roles and responsibilities influence the priorities that males and females have for basic urban services. Men's and women's different views and needs must be considered in any serious risk management framework. Women play an integral role in building, maintaining, and providing a safe, clean environment in human settlements and as contributors to the prosperity of cities through their paid and unpaid work within the household and communities. In this context, it is important to embed gender analysis and voice in community-driven efforts to manage risks and develop mitigation plans. While research is still limited on how gender issues are incorporated in GI development, many experts believe that gender and other sociocultural dimensions are crucial and must be recognized from the outset in programs related to climate change *(Schipper and Langston 2014)*.

CASE STUDIES

Six case studies from different countries provide insights into implementation of GI solutions in different settings. In some settings, such as **Portland, Oregon** (in the **United States**), a comprehensive citywide approach is evident. The case studies show that some locales explore GI options in direct response to increased flooding, while others do so as part of a wider effort that goes beyond flood management and encompasses lifestyle benefits.under environmental protection.



CASE STUDY 1. PORTLAND OREGON, UNITED STATES: *A CITYWIDE COMPREHENSIVE GI PROGRAM*[6]

Context: Portland is the biggest city in the northwestern state of Oregon. It is located in the Willamette valley and at the confluence of the Willamette and Columbia Rivers. With over 600,000 people, Portland is the 28th most populous city in the United States. The city has a history of major floods, including the great flood of 1894. To protect itself from flooding, the city built a seawall that stands at over 30 feet. A series of dams on the Willamette River also protects the city. In 1996, a massive flood struck Portland, caused millions of dollars in damage, and affected hundreds of thousands of residents. Since then, Portland has taken a number of steps toward flood risk management. The city is now a prime example of green stormwater management.

Approach: Portland adopted a comprehensive, multifaceted approach to GI solutions that focused attention on regulations, technology, one-off programs, incentives, and results monitoring. The benefits of such an approach are evident.

Source: City of Portland Environmental Services, https://www.portlandoregon.gov/bes/article/414873.

Regulatory Framework: Portland's Stormwater Management Manual and Code outline requirements that apply to all public and private projects in the city. For all projects that seek to develop or redevelop over 500 ft2 of impervious surface, the city requires pollution reduction:and runoff control standards. On-site infiltration (or temporary capture and storage of rainwater) is required as long as it is practical.

Building Technologies: Portland has experimented with a variety of building techniques. These include rain gardens, porous pavements, rainwater harvesting, planters, and disconnected downspouts (which feed water into permeable surfaces such as lawns). These techniques are visible throughout the city and in many different settings such as apartment buildings, schools, parks, government buildings, riverside esplanades, and other public spaces.

Incentives for Ecoroofs: The City of Portland provides a floor area bonus for green roofs—or ecoroofs, as they are referred to in Portland. The idea is to incentivize residents to create an ecoroof in exchange for an increase in a building's allowable area. Between 2009 and 2014, Portland's "program included over 330,000 square feet of ecoroof installations with a total private investment of over US$6 million" (City of Portland Environmental Services 2014).

Green Streets Program: In 2007, Portland's City Council adopted a Green Streets Program "to incorporate the use of green street facilities in public and private development." This program enables use of vegetated facilities to capture some of the stormwater on site, which also helps overall water quality and recharges groundwater. Green streets can be part of attractive, pedestrian- and bicycle-friendly streetscapes that create pleasant environments and improve citizens' quality of life.

Implementation and Monitoring: A key part of implementing Portland's comprehensive program has been to monitor progress and compile good practices. Portland's process of iterative learning from experience has allowed the city to establish a highly functional hybrid stormwater system.

Results and Lessons: According to the U.S. EPA (2010, 53), Portland has "one of the most mature and comprehensive GI programs in the country." The program has helped to mitigate the costs of major gray stormwater infrastructure initiatives; city officials estimate that a mere US$9 million in GI investments saved US$224 million in combined sewer overflow costs, such as repairs and maintenance. In terms of lessons offered by Portland's experience, the EPA suggests that while costs of implementing GI solutions are relatively straightforward, enumerating monetary benefits is challenging. To address this difficulty, project proponents should ascertain data on water storage and infiltration capacity of other GI solutions projects. In addition, it is useful to have estimates of alternative engineering solutions that decision makers can have for comparison. To estimate economic value of GI solutions, the EPA recommends using a tool designed by the Center for Neighborhood Technology (CNT 2010).

CASE STUDY 2. SINGAPORE: *ACTIVE, BEAUTIFUL, CLEAN (ABC) WATERS PROGRAM*

Context: In the 1960s and 1970s, Singapore witnessed frequent flooding, especially in the low-lying city center. These floods caused widespread disruption and damage. To reduce the risk of flooding, Singapore traditionally relied on a network of canals and rivers to channel water into reservoirs and into the sea. The city launched major projects to enlarge natural waterways such as the Kallang River and to line riverbanks with concrete to improve conveyance of water and reduce bank erosion. However, concrete waterways came with their own disadvantages, such as increased downstream peak flows and lack of habitat to support healthy aquatic ecosystems.

Approach: The government decided that a more sustainable approach was needed and developed a strategy to treat stormwater as close to its source as possible before discharging the treated water into public drains. A comprehensive, environmentally friendly water management system starting taking shape at the turn of the century. With a vision of transforming Singapore into a "city of gardens and water," the national water agency (PUB) launched the ambitious Active, Beautiful, Clean Waters (ABC Waters) program in 2007. While the vision inspires images of sparkling waters, landscaped banks, and clear water flowing into picturesque lakes, the ABC Waters program is much more than that. It is a new model for stormwater management as an integral part of overall sustainable water management. The ABC Waters program encourages design features that mitigate the impact of urbanization. These features, including rain gardens, bioretention swales, and wetlands, have not only improved water quality but have also increased biodiversity in the surrounding areas. The rainwater harvesting carried out under the program has allowed storage of water for later, nonpotable use such as irrigation or washing clothes. Projects under the ABC program follow guidelines relating to surface water drainage, flood control, stormwater quality, and public health risks. Projects are also guided by specific regulations. Singapore has identified over 100 potential locations for the implementation of the program by 2030.

Source: PUB Singapore's National Water Agency. https://www.pub.gov.sg/abcwaters.

Results and Lessons: An assessment of the Singapore ABC Waters program and similar initiatives found that the city "is well protected against floods" *(World Bank 2012b, 43)*. The assessment found further that flood-prone areas in Singapore have decreased substantially, from 629 ha (in 1989) to 56 ha (in 2011). By 2015, 32 ABC Waters projects were complete. Private developers completed another 54 "ABC Waters certified" projects (PUB 2016). Singapore's 3P (People, Public, Private) Partnership program has also increased public awareness of flood risk and the need for adaptive management *(World Bank 2012b)*.

Cities around the world have much to learn from the Singapore experience. A total water management strategy provides an integrated solution to multiple interconnected water issues, and a well-designed and targeted program implemented by dedicated institutions can deliver successful outcomes, such as reduced flood risk and adaptation to climate change. Singapore's 3P Partnership is a good example of how to involve different stakeholders from civil society. Finally, restoring a natural water system can be cost-effective because it lasts over a long period of time; this is evident in the Sengkang floating wetlands and Kallang River–Bishan Park *(World Bank 2012b)*.

CASE STUDY 3. SPONGE CITIES, CHINA: *COUNTRYWIDE PROGRAM TO REDUCE FLOOD RISK THROUGH WATER ABSORPTION*

Context: Three decades of economic growth has transformed China's cities. But this growth has come with obvious risks. One major risk is that cities are more vulnerable to disasters such as floods because the built-up environment is unable to absorb stormwater in the event of major rainfall. Chinese cities are flooded regularly. In July 2012, a major flood struck Beijing, killing 79 people and inflicting economic losses of almost US$1.9 billion. Overall, the flood affected 1.6 million people. The Beijing example is not an isolated one. According to the Economist, flood events in Chinese cities have doubled since 2008; and in 2013, almost 200 cities were flooded at one point or another. These occurrences highlight the risks faced by almost 700 million people who call Chinese cities home.

Approach: For many years now, China has been experimenting with low-impact designs that focused on absorbing, cleaning, and draining water in areas of impact. Tianxu Garden, a Beijing housing block, benefited from such design considerations: in the 2012 flood, the apartments in this area easily survived (O'Meara 2015). In September 2015, the Chinese government approved the development of 16 model "sponge" cities that would use ecologically friendly technologies to promote absorption and reuse of rainwater. To support infrastructure retrofits using green technologies under this initiative, the Chinese government will provide each sponge city US$63 million annually for three years.

A family at Cixi wetlands in Zhejiang Province. After restoration, the Cixi wetlands has become a place that local residents can enjoy.

Source: You Ji / World Bank, https://www.flickr.com/photos/worldbank/8771098606/in/album-72157603947675874/.

Results and Lessons: Experts are still in the process of assessing the sponge city initiative and its implementation arrangements. According to a report in the Guardian newspaper, the government's goal is to manage 60 percent of rainwater that falls in Chinese cities. The government wants to achieve this goal—a major undertaking—in the next few years, even as questions have arisen about financing arrangements needed to make investments in sponge cities sustainable. This concern notwithstanding, the Chinese sponge city initiative provides very public support for exploring alternative approaches, and does so as cities around the world work to reduce risks and avoid losses that may increase as climate change intensifies flood events.

CASE STUDY 4. COLOMBO, SRI LANKA:
GREEN INFRASTRUCTURE AS PART OF AN INTEGRATED FLOOD RISK MANAGEMENT PROGRAM

Context: The Sri Lankan capital city, Colombo, faces an increasing risk of flooding. For national and local officials alike, safeguarding the country's economic engine as well as the health of the city's 2.5 million inhabitants is now a top priority. After Colombo experienced severe flooding in 2010, the city's vulnerability to excessive rains was exposed. With experts linking shifting patterns of rainfall to climate change, Colombo decided to look into longer-term measures to reduce risks of natural disasters.

Approach: The Metro Colombo Urban Development Project is the centerpiece of the city's efforts to strengthen its resilience to floods. Supported by the World Bank, the project has made a range of improvements to the city's flood and drainage management system. What is different about this major project is its recognition of another serious challenge facing the city, loss of water storage capacity. Colombo, built on a low-lying river estuary overlooking the sea, has lost 30 percent of its basin water storage capacity in the last 10 years. The proximate cause is the growth of the city. This led to a project design that also focuses on demonstrating how restoring lakes and wetlands—which act as natural retention areas for sudden deluges, serve as natural water treatment plants, and help lower temperatures—could further increase the city's resilience to floods and potential climatic changes.

Baddagana Wetland Park.
Source: World Bank/Andrina Fernando, http://www.worldbank.org/en/country/srilanka/brief/beddagana-wetland-park-fact-sheet.

One of the key concerns of the project has thus been to review investments in wetlands. In addition to playing a role in flood management and water treatment, wetlands are also a recreational resource for local residents and for tourists, who are a major source of revenue for Colombo. In this context, the project provides US$11 million to complement flood mitigation measures in different areas, including the Beddagana Park wetlands. The specific objective here is to explore ways to protect the 32 ha wetlands from further encroachment due to urbanization, to preserve the water retention capacity of the wetlands, and to enhance Beddagana Park's recreational value.

Results and Lessons: It is still early in the project cycle to review the lessons learned or the full set of results achieved. However, a preliminary survey of residents reveals that satisfaction with Beddagana Park, Beira Lake Development, and related areas has increased, up from 68.5 percent in 2014 to 75 percent in 2015.

CASE STUDY 5. BEIRA, MOZAMBIQUE:
ADAPTING TO CLIMATE CHANGE IMPACTS IN COASTAL ZONES[13]

Context: Mozambique is among the African countries hardest hit by extreme hazard events such as floods, cyclones, and droughts. With climate trends expected to worsen the situation in Mozambique, the government has teamed up with international partners such as the World Bank and KfW Development Bank to explore an integrated DRM framework in vulnerable areas.

One of the areas where the Mozambique government is exploring use of GI solutions is Beira Mozambique's second biggest city. Some of the biggest ports in the country are in Beira, which is just above sea level. Beira is also host to many densely populated informal settlements with limited basic infrastructure for water and wastewater. This situation creates vulnerabilities. Moreover, flooding is a regular feature in the event of severe rains and leads to siltation around the fishing port, and in the Chiveve River. The mouth of the river is now blocked because of degraded drainage channels, the result of sedimentation caused by rains and floods.

Approach: To support Beira and other cities in reducing climate-related risks, the World Bank and the Pilot Program for Climate Resilience (PPCR) are financing the Mozambique Cities and Climate Change Project, with parallel financing from the German Cooperation through KfW. In Beira, the project's approach includes rehabilitation of the Chiveve River and development of urban GI to help restore the functioning of natural drainage channels and complement the renovation of the open canal system.

The rehabilitation of the Chiveve River is almost complete. Supported by a financial grant from KfW, the design included these elements:

- Rehabilitation of the Chiveve riverbed and riparian vegetation to restore the drainage function of the tidal river
- Construction of a tidal outlet at the fishing port to regulate the river's discharge and influx
- Dredging of sediments in the fishing port to ensure tide-independent port access

Results and Lessons: Clearing the riverbed of waste and dredging will help restore natural drainage capacity. The dredging of the backwaters and the port area is an additional precaution against flooding. Some of the GI investments proposed under World Bank assistance include the creation of a walking/biking pathway through the mangrove vegetation along the 3.5 km length of the Chiveve River. In addition, investments in landscaping will help improve and expand the green coverage, creating basic urban amenities that also help define the area available for public use and under environmental protection.

The program's likely impact will be to keep the Chiveve River at the core of the city's natural drainage system. Protection against floods is expected to improve, and there will likely be more space for new residential and commercial construction.

CASE STUDY 6. EKOSTADEN AUGUSTENBORG, SWEDEN: *GREEN INFRASTRUCTURE AS AN AID TO URBAN REJUVENATION* [14]

Context: In the 1980s and 1990s, Malmö, Sweden, was a physically dilapidated, economically challenged, and socially deprived region. Floods routinely impacted the area because the drainage system was inadequate. Health problems were severe and unemployment was high.

Approach: In 1998, the Augustenborg District in Malmö initiated an extensive urban renovation program under the name of Ekostaden (eco-neighborhood). Under this approach, officials sought to recreate the area as an integrated whole and to transform it into an ecologically, socially, and economically sustainable city district. Collaborating with area residents and other stakeholders, local officials succeeded in building a new neighborhood with public space and community-run cafes and activities. One of the most important features of this initiative was the use of green roofs to solve some of the flooding problems the area faced. The green roofs have been highly effective in capturing runoff, and on average intercept half of the total runoff over the course of a year. A botanical roof garden covers 9,000 m2 of the industrial area and contributes to the flood risk reduction efforts.

Source: The Urban Report (blog), "Welcoming Water (part 2): How Open Storm Water Management Works, "September 3, 2011, https://urbanreport.wordpress.com/2011/09/03/welcoming-water-part-2-how-open-storm-water-management-works/. Website:https://urbanreport.wordpress.com/2011/09/03/welcoming-water-part-2-how-open-storm-water-management-works/ https://urbanreport.wordpress.com/2011/09/03/welcoming-water-part-2-how-open-storm-water-management-works/https://urbanreport.wordpress.com/2011/09/03/welcoming-water-part-2-how-open-storm-water-management-works/

Results and Lessons: An evaluation (Kibirige and Tan 2013) concluded that the "open stormwater system in Augustenborg is well suited to handle current climatic conditions and a 10 year extreme event. The 100 year extreme event posed the most risk to the area and flooding was evident" (iv). The project has reduced runoff, created energy savings for residents, improved biodiversity in the region, and led to socioeconomic benefits such as a drop in the unemployment rate. The project continues to evolve based on lessons of experience, and institutions have come forward to support it. The Green Roof Institute in Augustenborg monitors the increase in green urban spaces and rainwater movements, and its efforts will be an important part of sustaining the successes achieved so far.

IMPLEMENTATION CHALLENGES

Challenges to implementing GI solutions are significant.

Any discussion about the potential benefits of GI would be incomplete without a treatment of the potential challenges its adoption faces. The most important obstacle appears to be the lack of systematic information on the efficacy of GI. A related challenge is the difficulty of allocating resources to an approach whose returns on investment are not as well documented as they are for gray infrastructure (University of Maryland 2013). There are many researchers who have attempted to document success stories, and some of the case studies presented in this note add to the body of evidence. However, it is important for practitioners to acknowledge this challenge and focus on strengthening the evidentiary base to assist policy makers in properly assessing the costs and benefits of adopting GI.

Currently, the measures commonly suggested for flood risk management are almost reflexively of the gray infrastructure variety.

This remains true even though no two floods are exactly alike. Many institutional, cultural, and public perceptions were formed at times when traditional engineering solutions were the norm, and these can prove a formidable obstacle to a more comprehensive integrated flood risk management system that considers and evaluates GI and other non-traditional solutions (Harries and Penning-Rowsell 2011). The reliance on gray infrastructure has proved enduring, even though these solutions—which focus on containing rivers and directing runoff away from natural courses—have failed in some heavy rainfall events. A further difficulty is that GI solutions often require investments from multiple policy fields and stakeholders, and this requirement calls for innovative multi-stakeholder investment schemes and budgeting. The resulting complexity can lead stakeholders to approaches they are more familiar with.

GI also faces technical challenges, just as gray infrastructure does.

For example, in some areas, the soil may not drain much or the location of proposed GI may be too steep. Limited space in densified cities poses practical difficulties as well. In addition, capacity issues—such as insufficient experience with GI practices—may exacerbate technical challenges. Compared to gray solutions, GI as an approach to urban flood risk management is relatively new. That implies limited availability of good practice examples, as well as fewer opportunities to create design standards and manuals for engineers, urban planners, and developers. One major aspect of this challenge is a lack of knowledge about maintenance of GI solutions.

Legal and regulatory challenges to the adoption of GI should not be underestimated.

Building codes, health codes, dimensions of urban streets and alleyways, and existing arrangements for parking and drainage may make it easier for municipal authorities to stay with technologies that they are used to, in this case gray infrastructure (Woolson 2013). In many developing countries, infrastructure spending is accompanied by leakages that may be advantageous to some officials and could encourage blocking of GI, which can be a less costly option. These are some of the practical legal and regulatory difficulties of introducing GI that must be taken into account by policy makers, practitioners, and advocates.

Challenges arising from ingrained perceptions also pose a serious barrier to GI adoption.

Officials in urban centers may find it difficult to fund GI projects due to perceptions about costs of construction and maintenance and limited information about demonstrated benefits. Even in developed countries, there may not be funds for designing and testing large-scale projects. In developing countries, finances are even more limited. This challenge is exacerbated by the limited evidentiary base for GI projects, since it is difficult to change perceptions in the absence of data.

RECOMMENDATIONS AND CONCLUSION

In recent decades, the theory and practice of DRM have evolved dramatically.

There is now a much greater focus on disaster preparedness, risk mitigation, and climate adaptation than on response mechanisms alone. One of the fundamental tenets of modern DRM, especially as it relates to floods, is to employ both structural measures, including GI solutions, and nonstructural measures, such as policies, regulatory frameworks, and capacity building programs. In the context of floods, structural measures have for a long time meant engineering solutions—dams, levees, canals, and similar infrastructure. These have clearly served a purpose and saved many lives and valuable assets. Changes in the underlying drivers of big events or recurring floods, however, are forcing stakeholders to rethink the efficacy of gray infrastructure alone in protecting people and property, especially in rapidly urbanizing landscapes.

This note argues that GI solutions should be actively considered as part of overall urban flood risk management frameworks.

The scale of modern disasters is linked to the movement of people from rural to urban areas, their settlement in vulnerable parts of cities, and the rising intensity and frequency of severe weather events. In many parts of the developing world, where floodplains are choked, water bodies are losing their absorption capacity, and populations and economic activity are much more concentrated, vulnerabilities are increasing. Policy makers in many countries have responded by incorporating GI solutions as part of a broader flood risk management framework.

Mainstreaming GI solutions in risk management frameworks, however, will require much effort.

It is here that institutions such as the World Bank can make a positive difference in efforts to mitigate risks of urban floods as well as to improve urban living conditions. For today's policy makers, past experience with gray infrastructure may create a barrier to adoption of new methods. The shift in mindset that allows serious evaluation of GI solutions will require more than lessons of experience from other countries. Evaluations should reflect the important role of local conditions (e.g., climatic context) in the effectiveness of certain measures. A one-solution-fits-all approach will not work. What modern policy makers are looking for is evidence that supports adoption of GI solutions for modern cities teeming with people and economic activity. For some policy makers, cost analysis will be important, while for others hydrological models to assess water evacuation and absorption efficiency will drive decision making. Thus more research and data collection are needed to provide systematic cost-benefit analysis as well as technical specifications of GI solutions. Green spaces in many cities are a sight for sore eyes, and the aesthetic value of GI solutions only adds to their overall appeal. Demonstrating the efficacy of green spaces in evacuating water within a river's natural catchment area is also critical. But quantifying the benefits of GI remains complicated.

Practitioners should think of GI as a complement to gray infrastructure.

Both have a role to play, and the need for either varies according to the dynamics of a particular situation. What is not in doubt is that GI solutions should be considered as part of the evaluation process in any major urban flood risk management program. That is a reasonable goal practitioners can set for themselves. With an increasing number of cities adopting GI solutions to mitigate urban flood risk, the body of evidence that informs decision making in city governments is also growing.

KEY RECOMMENDATIONS FOR OVERCOMING IMPEDIMENTS TO GI IMPLEMENTATION:

- ***Holistic GI solutions framework***. In promoting use of GI solutions in a city, consideration must be given to the full range of factors affecting implementation. These include the legal and regulatory framework and technical details as well as costs and benefits. In that sense, GI solutions should be treated as any other infrastructure solution.
- ***Cost-benefit analysis.*** Practitioners should be prepared to provide full cost-benefit analysis for proposed solutions. Costs and benefits may seem obvious, but in practice, the analysis may be complicated to carry out. The costs associated with GI solutions are relatively straightforward. However, the monetized benefits are more challenging to compute. Even so, identifying and cooperating with beneficiaries (in many cases public representatives of groups of beneficiaries) is important. There are tools to help guide the process, as indicated in the "Results and lessons" section of case study 1.
- ***Technical designs.*** Municipal authorities are used to reviewing design specifications of infrastructure projects. For GI solutions, a similar process can be engineered. From details of the hydrology of a particular area to calculations of groundwater infiltration

or runoff, technical specifications of GI solutions projects can be developed. GI design guidelines are available from a variety of sources, and these can be adapted to local conditions.

- ***Community and private sector participation.*** It is important, as some of the case studies suggest, to involve local communities and the private sector in implementing GI solutions. In addition to the core function of mitigating flood risk, GI solutions also provide intangible benefits such as a pleasant environment for community members to live in. Involving them from the very beginning can create sustainable community ownership of GI projects.

- ***Selectivity.*** As with other flood risk management solutions, limited resources require decision makers to be selective about implementing GI solutions. Site location, which is strongly related to technical design, is a key consideration for purposes of selectivity. For example, open sites that also have higher levels of soil infiltration will be better candidates for GI solutions.

We also note here some gaps in knowledge that hamper progress on GI solutions projects as well as areas that require additional research or greater consideration.

It is in addressing these gaps that institutions such as the World Bank can play a critical role.

- ***Limited city-level data.*** While there is a large volume of data on disasters at the global and country levels, there is a need to strengthen disaster and risk data at the city level. More data on potential disaster impacts and on mitigation effects of GI will help develop an evidentiary base for policy makers.

- ***Insufficient analysis of GI.*** More work needs to be done on the role of GI solutions in reducing poor communities' vulnerability to floods. Practitioners could also analyze the value urban communities place on the environmental and social benefits of GI—that is, those beyond its role in flood management. This analysis requires collaboration of DRM practitioners with experts from other fields such as urban development, governance, public health, and poverty.

- ***Inadequate treatment of gender issues.*** The treatment of gender issues in urban flood management is still sporadic. As we learn more about gender issues in natural disasters, we should review the applicability of findings to urban settings, and seek to understand whether urban and rural settings differ where gender issues are concerned. Within this context, it would be informative to analyze GI adoption from a gender perspective to understand if men and women approach or value these solutions differently.

- ***Insufficient knowledge sharing and use of existing research.*** The DRM community must itself become much more aware of the state of the art in urban flood risk management. Institutions such as the World Bank have for a long time promoted development that is environmentally sustainable and that protects biodiversity. When this past experience informs future work in GI solutions, country dialogue improves, and practitioners are better able to show policy makers the costs and benefits of GI solutions.

Overall, despite knowledge gaps, there is much evidence that the role of GI solutions will grow for urban flood risk management. Along with gray engineering solutions, GI solutions will be an option for policy makers as they confront challenges of urbanization, poverty, and natural disaster risk. Practitioners, including those at institutions such as the World Bank, will play an important role in promoting GI solutions, especially for sustainable development and in partnership with local communities.

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[12] This case study is adapted from KfW Development Bank and World Bank project documents.

[13] This case study is adapted from European Commission (2013).

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